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PB97-112866

WT-782

This document consists of 232 pages
No. 2E7 of 275 copies, Series A

Report to the Test Director

SUMMARY REPORT OF THE TECHNICAL DIRECTOR

Programs 1–9 (U)

Headquarters, Field Command
Armed Forces Special Weapons Project
Sandia Base, Albuquerque, New Mexico
March 1955

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TABLE 1.1—Summary Data for All Shots

	SHOT 1	SHOT 2	SHOT 3	SHOT 4	SHOT 5	SHOT 6	SHOT 7	SHOT 8	SHOT 9	SHOT 10	SHOT 11
DATE	17 MAR	24 MAR	31 MAR	6 APR	10 APR	11 APR	25 APR	19 MAY	8 MAY	25 MAY	4 JUNE
TIME (GMT)	1320 00.328	1310 00.086	1259 59.995	1529 38.413	1234 59.958	1244 59.781	1229 59.763	1230	1529 55.362	1530	1115
LOCATION (AREA)	T-3	T-4	T-7-5a	T-7-3	T-2	T-4a	T-1	T-3a	FF	FF	T-7-3
YIELD (KT) RAD CHEM	16.2	24.5	0.20	11.0	23.0	0.22	43.4	27.0	26.0	14.9	60.8
CODE NAME	ANNIE	[redacted]	[redacted]	DIXIE	BADGER	RAY	SIMON	HARRY	ENCORE	GRABLE	CLIMAX
WEAPON	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
HEIGHT OF BURST (FT)	300 Tower	300 Tower	300 Tower	6022 Air	300 Tower	100 Tower	300 Tower	300 Tower	2423 Air	524 Air	[redacted]
HEIGHT OF BURST (FT) (SCALED TO 1 KT AT SEA LEVEL)	112.5	97.8	486.3	2377.5	99.6	157.2	80.8	94.8	764	203.6	316.6
GROUND ZERO-RELATIVE TO AIMING POINT (FT)				72 N 565 E					837 S 15 W	139 S 86 W	232 N 172 W
ATMOSPHERIC PRESSURE (mb)											
GROUND ZERO	876	870	873	861	862	869	870	874	900	901	867
BURST HEIGHT	866	860	863	686	852	866	860	864	825	884	824
AIR TEMPERATURES (DEGREE C)											
GROUND ZERO	2.7	9.9	4.4	15.5	7.7	-0.3	11.7	14.3	16.7	14.8	13.3
BURST HEIGHT	7.9	13.3	8.2	-0.6	7.2	-0.1	15.3	18.3	8.0	13.1	12.2
RELATIVE HUMIDITY (%)											
GROUND ZERO	43	39	48	25	40	43	26	35	19	32	30
BURST HEIGHT	38	32	32	36	39	40	26	36	23	23	38
SURFACE WIND-DIRECTION AND VELOCITY (KNOTS)	CALM	310 02	360 04	045 07	360 09	045 05	340 05	020 05	190 05	360 04	045 03
ATMOSPHERIC TRANSMISSION (%/mi)	94	94	95	92	93.7	95	95.7		92.5	91	93

[redacted]

ideal curve except for the uncertain region of transition from regular to Mach reflection.* In this case, where no precursor or other strong thermal effects were obtained, there is no apparent effect of dust loading, even though the measurements were made over a very dusty surface.

Figure 2.27 shows a typical dynamic pressure measurement in the precursor or thermal effects regions on Shots 1, 10, and 11. The erratic and limited nature of some of the q measurements is evident. Figure 2.28 shows the peak q measurements as compared to the ideal values for these three shots. Three data points are marked to show instrumentation saturation, with a strong likelihood that higher set ranges would show much greater peaks. The measured values of q in the strong precursor region are greater than ideal and much greater than would be calculated from the companion measured overpressures. At the outer limits of the precursor or thermal effects region, the measured values agree with ideal and are again substantially higher than would be calculated from the measured overpressures. In these latter cases it is likely that the effect of dust loading is small. However, the departure from the measured overpressure is also relatively small so no firm conclusion can be drawn. In the stronger precursor region, where the measured dynamic pressures are substantially greater than ideal, there is no means to estimate the quantitative effect of dust loading. It is not possible to conclude that the measured dynamic pressures would be ideal in the case of a precursor without dust ("organic"). Suffice it to say that it can be concluded that the Pitot-static tube dynamic pressures can be established as equal to or greater than ideal in the precursor region of low bursts over dusty desert surfaces. More full-scale test data are required to justify statements concerning the dynamic pressures of low bursts in the strong blast region over other surfaces.

2.7 PRECURSOR

2.7.1 General

Three of the instrumented UPSHOT-KNOTHOLE detonations, U-K Shots 1, 10, and 11, had pronounced precursors. The yields of the precursor shots ranged from about 15 to 60 KT, over a range of scaled heights of burst from 112 to 316 ft. This region of yields and burst heights is very favorable for precursor formation, and from a number of past operations it is known that the precursor region exists over a larger range of yields and burst heights than was represented by these three shots.

To obtain a general perspective of precursor formation and propagation, the high-speed photography yielded an excellent sequence of the various stages of the precursor shock waves, such an example being Fig. 2.29 taken on U-K Shot 11. The reflected shock wave is fully developed before there is any indication of a new pressure wave (precursor) propagating outward along the ground ahead of the reflected wave. The delayed appearance of the precursor is discussed in Sec. 2.4.3.3. Other excellent examples of the development and progress of precursor waves were prepared by NOL from shock photographs, such as Fig. 2.30 (U-K Shot 1) and Fig. 2.31 (U-K Shot 10). The precursor shock contours for U-K Shot 10 and U-K Shot 1 appear quite similar, although the pressure-time records are distinctively different (see Figs. 2.14 and 2.16). Thus similar precursor fronts can have quite different conditions prevailing on their interior. The vertical extent of the U-K Shot 1 precursor shock is rather impressive, being about 200 ft high at ground distances of about 1500 ft. The dust behind the precursor on U-K Shot 10 attains a height of 100 ft at 1300 ft ground distance. It is seen that a precursor would envelop com-

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*The q values calculated from measured overpressure in the regular reflection region of Fig. 2.26 differ slightly from those given in Report WT-714[5] (Fig. 1.12 and Table 1.10). The equation from which they were calculated, Eq. 1.3, should be corrected to read:

$$q \frac{2.5\ P_0}{\xi(\xi'+6)} \left[(1-\xi)\left(\frac{1+6\xi'}{1+6\xi}\right)^{1/2} \sin\alpha\ (\xi'-1)\sin\alpha'\right]^2$$

[redacted]

pletely very sizable aboveground structures. The ultimate height and ground extent of the U-K Shot 11 dust pedestal is shown in Fig. 2.32 and is seen to be very sizable. It is certainly more than coincidence that the dust pedestal terminates at about the end of the precursor region (radius 3400 ft). The likelihood of dust contributing to the loading in the precursor region is obvious from such a figure.

2.7.2 Thermal Layer

A sizable fraction of the total energy released from a nuclear detonation is emitted in the form of thermal radiation. Large amounts of thermal radiation are incident upon the ground before shock arrival; thus the existence of a thermal layer near the surface is a sound assumption. Experimental results are only indicative of a general high temperature layer of air existing prior to shock arrival. The early formation of a Mach stem and the variation of peak pressure with elevation above the ground indicate some thermal effects even on relatively high-scaled heights of burst, such as U-K Shot 9. At lower heights of burst, such as U-K Shots 1, 10, and 11, the thermal effects are very pronounced and result in the unconventional precursor pressure wave.

Actual measurements of preshock sonic velocities were obtained by the Navy Electronics Laboratory (NEL) on two TUMBLER and two U-K shots. Although the results are only fragmentary, such measurements indicate substantial increases in preshock sonic velocities. In addition to actual measurements, it is possible with some assumptions to compute the preshock temperatures using (1) the SRI method of arrival time of the shock wave propagating through the thermal layer vs ground distance and (2) the NOL photographic data for the angle of the precursor front above the thermal layer. The arrival-time data are used to determine shock velocity in the thermal layer, which, by use of known shock relations, leads to temperature. The NOL method of obtaining preshock temperature is based on a relation between sonic velocity in the thermal layer and the angle of the precursor front in the ambient air above the thermal layer.

Figure 2.33 presents the results of these computations of preshock temperature vs ground range for U-K Shot 10. At ground ranges less than 1000 ft, there is a significant difference in the temperatures computed by the two methods; however, the individual points are probably subject to errors of as much as ±25 per cent. It was possible to make similar shock velocity–preshock temperature computations for U-K Shot 11 (A-scaled height of burst, 316 ft); these results are plotted in Fig. 2.34 along with the experimental and computed results for TUMBLER 4 (A-scaled height of burst, 363 ft). The results from the two tests appear to compare favorably, indicating that average temperature values (at scaled ground ranges) may be comparable for shots detonated at about equal scaled burst heights; in addition, the TUMBLER 4 experimental curve [NEL and Naval Radiological Defense Laboratory (NRDL)] agrees well with the points computed by the shock velocity method (SRI).

2.7.3 Precursor Overpressure and Dynamic Pressure

Figure 2.35 compares U-K Shots 10 and 11 scaled pressure-time records at comparable scaled ground ranges. Although the peak pressures of the precursors and the second pressure peaks are not equal, there is a striking similarity in the general nature of the pressure-time records; Shot 10 was detonated at 202 ft (A-scaled) and Shot 11 at 316 ft (A-scaled). Further, comparison of U-K Shot 11 and TUMBLER 4, Fig. 2.36, which are shots not too different in scaled burst heights, results in almost identical pressure-time records both as to wave forms and as to values of peak pressure. To the extent that pressure-time records relate some of the general attributes of a precursor, U-K Shot 11 and TUMBLER 4 are nearly identical at the same scaled ground distances. It is to be noted that U-K Shot 11 and TUMBLER 4 were detonated over the same Yucca Flat terrain, whereas U-K Shot 10, which compares poorly with U-K Shot 11, was detonated over Frenchman Flat. One cannot conclusively say the differences in U-K Shot 10 and U-K Shot 11 peak overpressures at the same scaled distances are due to heights of burst, terrain, or combinations of both.

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The pressure-time records for U-K Shot 1 (Fig. 2.16) are quite different from those obtained on U-K Shots 10 and 11 in that generally the U-K Shot 1 overpressure in the first peak is more nearly equal to that of the second peak overpressure. Further, U-K Shot 1 has a first peak pressure higher than the second peak when the pressure levels are less than about 15 psi. This is in marked contrast to the previous pressure-time records for U-K Shots 10 and 11 and TUMBLER 4. Because U-K Shot 1 was detonated over the same Yucca Flat terrain as U-K Shot 11 and TUMBLER 4, the only reasonable explanation is that the differences are due to the height of burst.

Dynamic pressure measurements in the precursor regions of U-K Shots 1, 10, and 11 are rather fragmentary but unquestionably show that measured peak values are not related to the Rankine-Hugoniot values of dynamic pressure obtained from measured peak overpressures. Comparisons are given in Table 2.4.

TABLE 2.4 — Comparison of Measured and Calculated Dynamic Pressures in Precursor Region

Shot	Gage	Ground range (ft)	ΔP used for calculation	q, calculated (psi)	q, measured (psi)	q, measured (calculated)	q, measured (ideal)
1	84F10	1250	15.0	5.4	115	21	2.50
	85F10	1450	13.0	4.1	40	9.8	1.18
	89F13	2600	4.4	0.52	0.55	1.06	
			9.7	2.38	2.20	0.925	0.76
10	82F13	1169	30.0	18.4	>57	>3.1	>1.24
	17F10	1422	26.4	15.1	>9.6	>0.64	>0.38
	17F40	1422	12.9	4.0	>11.6	>2.9	>0.46
	00F10	1920	11.0	2.95	10.9	3.7	1.28
	00F25	1920	12.1	3.55	11.6	3.3	1.37
	00F40	1920	8.1	1.65	12.4	7.5	1.46
11	4F5	3435	5.24	0.74	3.0	4.0	
			11.5	3.3	5.92	1.8	0.97

Figure 2.37 shows the dynamic pressure-time records in the dusty precursor region attaining nearly peak values at early times when the overpressures are slowly rising. It is thought that the rapid rise of dynamic pressure can be associated with the arrival of the dust at the station. Typical dynamic pressure-time records, Fig. 2.27, obtained in the precursor region show very rapid fluctuations in amplitude, an attribute not present at later times nor in the nonprecursor records. This suggests a high degree of turbulence in the precursor portion of the pressure wave. The contribution of turbulence to damage could be important.

It is well documented by photography that the precursor front has an upward component of flow. Indeed, dust originating near the surface ultimately attains heights of 100 ft or more. It is thus concluded that an upward component persists at aboveground stations for a finite time. No quantitative data exist as to the actual durations of the upward component. An upward component of motion imparted to movable drag targets enhances the damage considerably because of repeated impacts with the ground.

2.7.4 Precursor Prediction Criteria

Subsequent to TUMBLER, several reports appeared in which attempts were made to set down a number of idealized assumptions and from these to obtain predictions as to what yields and scaled burst heights would result in a precursor. Two sets of criteria that deserve attention are found in the TUMBLER Summary Report WT-514[8] and a Sandia Corporation report

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by Shelton.[9] As will be seen later, these two prediction criteria differ as to precursor formation in several regions. The very strong precursors which occurred on U-K Shots 1, 10, and 11 would have been predicted by either of the above criteria. Operation UPSHOT-KNOTHOLE did not produce much relevant data from which more realistic prediction criteria could be developed. Actual temperature or sonic velocity measurements in the thermal layer are few, details of a thermal gradient with elevation are lacking, and, indeed, the exact mechanism for formation of the thermal layer is not defined.

The TUMBLER criteria, based upon empirical data, set limits on (1) scaled height of burst, (2) a yield-true height-of-burst relation (W/h^2), and (3) the time required for shock wave to reach Ground Zero. Shelton's criteria are based partially upon empirical data and partially upon theoretical analysis. Two important assumptions are made that merit review: It is assumed that velocity of sound in the thermal layer (at a particular ground range) is a linear function of the preshock normal component of the incident thermal radiation; it is further assumed that this relation is invariant from one test to another (TUMBLER-4 data are used for all calculations). The first assumption above takes no account of the fact that portions of the thermal layer are expanding and cooling continuously. The second assumption is admittedly approximate; U-K Shots 10 and 11 data deviate from those of TUMBLER-4.

A summary of the two precursor formation analyses is presented in Fig. 2.38. In this figure the thick cross-hatched curve is due to Shelton and separates the "precursor" and "no precursor" regions. Also on the figure are found the limit curves from the TUMBLER analysis. In comparing these two criteria, the most interesting difference is revealed by the fact that the TUMBLER report predicts precursor formation for low-yield weapons (1 to 2 KT) at A-scaled heights of burst from 50 to 400 ft, whereas Shelton's curve indicates that no precursor is formed for these weapons at any burst height. The other significant deviation between the two criteria is found in the region of 500- to 600-ft burst heights and yields larger than about 30 KT; there are no available data for this region.

It is evident that future tests are required to define more clearly the criteria for precursor formation. In this regard some of the important deficiencies in this field include a knowledge of preshock temperatures as a function of ground range and height above the ground; the effects of various surface conditions upon the formation of the thermal layer; and the influence of blast geometry (yield and height of burst) upon the shock wave in the nonideal region. It is clear that such tests must be supported by a comprehensive analytical program to include such theoretical and laboratory investigation as may be necessary to apply full-scale results to real surfaces of military interest.

2.7.5 Smoke Experiment Precursor Effects

A smoke experiment was conducted on U-K Shot 10 to study the manner in which a thermally absorbing black smoke layer would modify the normally expected thermal effects on blast. Figure 2.39 shows the pressure-time records obtained by the surface level gages along the main blast line and the smoke line. The effect of the precursor is to distort the shock wave by increasing its duration, reducing the peak pressure, and usually degrading the rapid rise time of the shock front to a slow rate of rise. In the precursor regions the peak overpressures under the smoke were higher than on the main blast line, and the pressure rise times on the smoke line were much faster than at corresponding ground distances on the main blast line. At 1632 ft and beyond the shock wave under the black smoke shows no precursor, whereas on the main blast line the precursor effects were evident to about 2700 ft. Peak pressure data for the smoke line are plotted in Fig. 2.40 and compared to the curve established for the main blast line. The peak pressures on the smoke line are very close to those predicted over an ideal surface at a ground distance of about 1600 ft and beyond, whereas on the main blast line peak pressures are reduced below ideal out to ground distances of about 3000 ft. Comparison of the pressure-time records and values of peak overpressure at corresponding ground distances leaves no doubt that the thermally absorbing black smoke significantly reduced the thermal effects on the blast wave.

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The gage towers that failed or bent are examples of damage to drag-sensitive targets. Thus, to some extent, it is possible to compare damage under the black smoke and along the main blast line. The 10-ft gage towers were blown down along the main blast line out to 2166 ft and bent at 2666 ft and were undamaged beyond this distance. Along the smoke line similar 10-ft gage towers were blown down out to 1133 ft and bent at 1632 ft, beyond which the towers were undamaged. It would appear that gage towers were blown down or bent out to edges of the nonideal regions.

The time of arrival of the initial disturbance along the smoke line and blast line is presented in Fig. 2.41. It is seen that in the precursor region the pressure signal arrives earlier along the main blast line. This indicates that the air temperature near the ground along the main blast line is significantly higher than along the black smoke blast line.

Summarizing, as compared to a clear area, the black smoke area on U-K Shot 10, through the mechanism of thermal-radiation absorption, greatly reduced the air temperatures near the ground. This, in turn, greatly reduced the thermal effect on blast, maintained blast parameters much more nearly ideal out to about 1600 ft from Ground Zero, and eliminated the precursor on the smoke line entirely beyond this ground distance. Damage to drag-sensitive targets may be reduced under the black smoke as indicated by the gage towers. Finally, a thermally reflecting white smoke would probably reduce the precursor effects even more than the thermally absorbing black smoke.

2.7.6 Thermal Shock

It has been speculated that the precursor shock was perhaps generated by thermal radiation being absorbed at the ground surface and also in the popcorned dust near the surface. Air suddenly heated to temperatures of the order of 1000°C would be at pressures in excess of ambient pressure. Thus a thermal shock would propagate outward as the hot air mass expanded to ambient pressure. Because of the time dependence of thermal radiation, a thermal shock precursor should not form immediately but more nearly at times after the arrival of the main shock at Ground Zero.

In Fig. 2.42 photographs are shown of laboratory experiments on the response of three types of thermal materials to a high-intensity thermal pulse. Only one of the media, namely, the Frenchman Flat adobe surface, underwent a popcorning transition, whereas the other two did not. The particles ejected from the adobe surface extended out to distances to the order of 6 to 10 in. for this laboratory experiment. These studies were conducted by the Naval Material Laboratory (NML) in cooperation with the David Taylor Model Basin (DTMB). Full-scale tests by means of 10 ft × 10 ft panels were conducted by DTMB on U-K Shots 9 and 10. There seemed to be a very reasonable correlation between the surface conditions of the laboratory and field test members. Pressure gages with high time-resolution characteristics were located in the field panels which yielded records indicating, in general, that significant pressure values are not associated with popcorning. As indicated by the preshock pressure-time signals of Fig. 2.43 and also reviewing the above DTMB experimental results, one may conclude that to a reasonable approximation there are no significant preshock pressures associated with popcorning effects and subsequent thermal radiation. The further conclusion may be drawn that although thermal shock may occur close to Ground Zero, it is not significant as a mechanism for precursor generation, inasmuch as it is only expected to occur under those conditions where the precursor will form at slightly greater ranges according to the heated layer concept.

2.8 TRIPLE POINT (MACH STEM CONSIDERATIONS)

2.8.1 General

Detailed data on the path of the Mach triple point near the ground were obtained on Shot 9 of UPSHOT-KNOTHOLE. In addition, the shock photography gave Mach stem data high above the ground surface (up to 500 ft) for Shots 1 and 10. No data on triple point path were obtained on Shot 11. Comparisons will be made between the Shot 9 data and similar measurements on

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TUMBLER Shot 1; also, it will be valuable to show how these nuclear data compare with Mach stem data obtained from TNT detonations.

2.8.2 U-K Shot 9 and Thermal Mach

Theoretical considerations of shock-wave configuration show that the ground range at which a Mach reflection begins is a function of the shock strength and the burst height. The theory predicts Mach reflection starting at a ground range about equal to the burst height. In the absence of surface and/or thermal effects, this prediction has been substantiated by experiment.

For U-K Shot 9, the Mach stem was expected to originate at about 2400 ft ground range. The Mach stem development, as determined from the data shown in Fig. 2.44, indicates the existence of a Mach stem as close as 800 ft from Ground Zero. It is to be noted that a relatively similar early development of a Mach stem was reported for the nearest scale 1.0 KT shot of TUMBLER 1. It appears plausible to attribute this formation characteristic to the presence of a thermal layer similar to the results of shock-tube experiments performed at Princeton. The incident wave impinging upon a thermal layer above the normal ground layer will undergo reflections at both the thermal boundary and the ground. If this is the case, there will be a region wherein a Mach wave develops in the thermal layer from the interaction of the transmitted shock with the rigid earth boundary. This is termed a "thermal Mach shock," since it is produced as a result of the bending of the incident shock due to the thermal layer and occurs before the incident angle of the incident shock wave is large enough to form a Mach stem in the absence of a thermal layer.

It is to be noted that the data points of Fig. 2.44 are based upon a series of extrapolations from arrival-time data, assuming a standard Mach stem configuration exists, namely, an incident, reflected, and Mach wave meeting at a point. The sensitivity of this data reduction method to arrival-time errors is indicated in Fig. 2.44 where limit bars are drawn from each data point corresponding to 0.5 msec deviations in Δt_{1r}. The dashed lines in the figure indicate the gross limits within which the Mach triple point trajectory existed on U-K Shot 9.

The A-scaled comparison of the Mach stem height vs ground range data from TUMBLER 1[10,11] and U-K Shot 9 is presented in Fig. 2.45. Although the data from TUMBLER 1 are meager, the agreement is good and the figure indicates that Mach triple point trajectory does scale in the ideal wave form region.

Figure 2.46 presents the results of photographic data[3] on Mach stem height vs ground range for U-K Shots 1 and 10. The U-K Shot 10 data indicate that a thermal Mach shock formed at close-in ground ranges before the extreme angle of regular Mach reflection was realized. For U-K Shot 1, the data do not extend to low enough ground ranges for any conclusions relative to the formation of the thermal Mach shock on this shot.

2.8.3 Nuclear Vs TNT

It is believed of value to present some summarizing analysis of Mach stem results to date with respect to nuclear tests. The basis for the summary will be comparisons of available nuclear data in the ideal shock region with the triple point curves (normalized to 1 KT) from Zirkind's recent report.[12] These curves, shown in Fig. 2.47, were obtained by taking the results of recent Ballistic Research Laboratories (BRL) Mach stem experiments with TNT charges, assuming a TNT blast efficiency of 50 per cent for nuclear charges, and replotting the data for various A-scaled burst heights. Using the curves of Fig. 2.47 as the basis of comparison accomplishes the purpose of reviewing the relation between nuclear and TNT Mach reflection characteristics.

The agreement between the curves of Fig. 2.47 and the GREENHOUSE Easy, U-K Shot 1, and U-K Shot 10 Mach stem data is good. However, as the height of burst of the nuclear charge is increased, the agreement becomes progressively worse. The TUMBLER Shot 4 (A-scaled height of burst = 363 ft) data give a curve in the ideal shock wave region corresponding to an A-scaled height of burst of about 400 ft; for U-K Shot 9 and TUMBLER Shot 1 (A-scaled height of burst = 750 ft), the triple point data agree with a TNT equivalent height of burst in excess of

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900 ft; for TUMBLER Shots 2 and 3 (A-scaled height of burst = 1000 ft), the agreement is poorer yet.

The general conclusion from the foregoing is that for low A-scaled burst heights (less than about 300 ft) the nuclear Mach stem data compare favorably with the curves from TNT. However, as the A-scaled burst heights are increased, the nuclear results correspond to triple point trajectories that would be predicted for TNT charges detonated at significantly higher heights of burst. The foregoing general conclusion is substantiated by the Air Force Cambridge Research Center (AFCRC) canister measurements, which determined some points on the triple point path at very high altitudes.

2.9 HEIGHT-OF-BURST CURVES

2.9.1 History

The original concept of the height-of-burst curves was to assist military planning groups in determining the most efficient utilization of atomic weapons for operational situations. An early requirement had been established for information relating the height of burst to blast effects at various ground ranges in order to select the proper yield and conditions of detonation for atomic weapons. Peak overpressure was selected as the most representative blast parameter in relation to damage criteria based largely on Japanese experience. The first set of height-of-burst curves were those prepared in 1949 by means of an analytical treatment of conventional shock-wave theory, small-scale HE and shock-tube experimental results, along with the nuclear air blast data for Bikini Able measured along the surface. These curves gave values of peak overpressure vs ground range as a function of height of burst for 1 KT (RC). The normal cube root scaling laws for blast phenomena were assumed valid in applying these curves to other weapon yields. In addition to operational planning, these curves were also used to provide criteria for weapon development.

It was noted in 1951 that air blast pressure measurements on both SANDSTONE and GREENHOUSE gave somewhat lower values than those predicted from the height-of-burst curves. These results did not appear to have serious operational significance since these tests involved only tower shots. However, plans were made to measure air blast pressures for the four air bursts of BUSTER.

The BUSTER results in the high-pressure region were very much lower than those predicted from TM 23-200 (1 October 51). Consequently, Supplement 1 to this publication was issued on 8 February 52 to provide the DOD with new height-of-burst curves on an interim basis. These curves, labeled good, fair, and poor, included pressure reductions based on theoretical consideration of both thermal and mechanical effects. Simultaneously, planning proceeded for TUMBLER during which it was proposed that comprehensive measurements of blast and thermal radiation be made following the detonation of different yield atomic weapons at various heights. In particular, data on peak overpressure gathered by different groups would be correlated to prepare new height-of-burst curves. The experimental program was also designed to provide enough scientific information on the nature of the blast wave to permit the application of the TUMBLER results to more realistic target areas.

The results of TUMBLER are presented in Report WT-514, Final Summary Report.[3] An empirical set of height-of-burst curves was prepared, based primarily on ground-level pressure measurements for the TUMBLER shots. The blast data from the TRINITY, SANDSTONE, and GREENHOUSE tower shots, as well as the JANGLE surface shot, were used to obtain the zero height intercepts and the general nature of the contours for low burst heights. In the region above a scaled height of 1000 ft, where there were no full-scale experimental data at that time, a theoretical treatment of the TUMBLER free air pressure-distance relation was used to complete the curves.

A shaded area was presented in these curves to indicate the region of blast-wave distortion due to thermal effects, which were particularly evident on TUMBLER 4 where a precursor developed. For those weapon yields and heights of burst for which precursor effects are signifi-

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cant, it was recommended that pressures in the shaded area be reduced by $^1/_3$ for certain unfavorable target conditions, such as extremely dusty areas. For those areas considered to represent favorable target conditions, such as water surfaces, pressures in the shaded area might be increased by as much as $^1/_6$. With these reservations, the TUMBLER height-of-burst curves were included in TM 23-200 (1 October 1952) for use in operational planning.

2.9.2 Philosophy

The philosophy of the TUMBLER height-of-burst curves was to use peak pressure as an arbitrary standard of reference since it was a physical effect easily measured and was considered to be the single phenomenon of importance in determining the effect of loading on a large class of important targets. At that time it was realized that several other parameters could just as easily be used for height-of-burst curves, such as dynamic pressure, particle velocity, density, or temperature, since these are interrelated properties of conventional pressure waves. Therefore it was generally understood that inherent in the designation of the pressure level was also the specification of the relative values of the other associated physical effects related by classical theoretical equations for ideal shock waves. Consequently, it was intended that the height-of-burst curves be used in conjunction with tabular data correlating type of structure, degree of damage, and corresponding peak pressure level in order to specify damage criteria for a variety of weapon sizes and heights.

During TUMBLER, a few dynamic pressure measurements were made. However, there appeared to be no significant departures in these measurements from what would be calculated from measured overpressures since values of q were obtained for high burst heights where thermal effects on the blast wave were minimized. As a result, the significance of dynamic pressures in the nonideal region for low bursts was not recognized. It was believed that the significant reduction in peak pressure and the badly distorted wave form might seriously reduce damage in the region near Ground Zero.

As noted previously, during UPSHOT-KNOTHOLE, several agencies participated in studying basic phenomena in order to supplement available full-scale data and permit a better understanding of the fundamental blast effects associated with air bursts of nuclear weapons. In order to investigate more fully the nonideal region, Program 1 included measurements of both overpressure and dynamic pressure for Shots 9 and 10, as well as preshock sound velocity over various surfaces. As a result of these measurements, it was clearly evident that the classical relation between p and q was no longer valid in the precursor region for low bursts. The measured values of q were considerably higher than would have been calculated from measured values of p by use of the Rankine-Hugoniot equations. It was subsequently found that the Pitot-static tube was susceptible to the effects of dust; thus the measured q values include the dust loading present in the shock wave. This fact must be considered in comparing measured q values to the ideal. The ideal height-of-burst curves for peak overpressure and dynamic pressure shown in Figs. 2.8 and 2.9 assume a perfect reflecting surface with no perturbations to the blast wave resulting from dust or thermal effects. The deviation of the UPSHOT-KNOTHOLE experimental data from the ideal as a function of height of burst will be discussed below. The surface-level pressure data (A-scaled) for Shots 1, 3, 4, 9, 10, and 11 are shown in Fig. 2.48.

2.9.3 Air Overpressure

Figure 2.49 presents the ideal peak air overpressure height-of-burst curves (Fig. 2.8) with the U-K data points included on the figure. A few pertinent general comments can be made with reference to this figure.

The experimental values of peak overpressures for Shot 9 appeared to agree well with the ideal curves for values of overpressure equal to 6 psi and below. However, even for this relatively high height-of-burst shot, there are significant deviations from the ideal at higher overpressures. For U-K Shot 1 (112 ft A-scaled burst height), Shot 10 (202 ft A-scaled burst height), and Shot 11 (314 ft A-scaled burst height), the data points for overpressures of 8 psi and lower seem to agree quite well with the ideal curves. However, in the stronger shock regions (10 to

[redacted]

50 psi) the deviations from ideal are marked. In particular, the points from Shot 1 corresponding to this stronger shock region indicate a serious reduction in overpressure for this low height of burst. If one is to retain the zero height-of-burst intercepts as obtained from the JANGLE surface experiment, then it is evident that the height-of-burst curves near 100 ft A-scaled height must exhibit a sharp inflection or "knee."

It would appear from the UPSHOT-KNOTHOLE results that there still remain uncertainties with relation to the nonideal region of the height-of-burst chart for peak overpressure.

2.9.4 Dynamic Pressure

The dynamic pressure height-of-burst curves for ideal conditions as presented in Fig. 2.9 were constructed using a peak air overpressure ideal height-of-burst chart and the classical shock-wave relations. It should be pointed out that there is a necessary ambiguity existing for dynamic pressure calculations near the region of transition between regular and Mach reflection. In this transition zone one may obtain a discontinuity in the dynamic pressure curves. For this reason it was necessary to fair in the curves of Fig. 2.9 near this transition region. In addition, by definition, the dynamic pressure approaches the value zero at Ground Zero; therefore it was necessary that these height-of-burst curves agree with this restriction.

The UPSHOT-KNOTHOLE experimental dynamic pressure results are indicated in Fig. 2.50 for Shot 9. The agreement with the ideal curves is quite good, the result which might be expected on the basis of small thermal effects experienced on this shot. It is evident that the peak dynamic pressures show significant scatter as compared to similar data taken for peak overpressure.

For the lower burst height, Shots 1 and 10, the comparisons with the ideal curves yield similar results. For dynamic pressures less than about 3 psi, the data, although meager, agree well with the ideal. However, for dynamic pressures of 10 psi and larger, the measurements indicate that the values are significantly higher than would correspond to ideal conditions. It should be noted that on Shot 10 three gages from which dynamic pressures were obtained indicated that they were overranged. In addition, the Pitot-static tube is sensitive to dust; therefore q measurements in the nonideal region for Shot 10 are necessarily limited in their significance. For Shot 11, a high-yield device at an A-scaled height of burst of about 300 ft, the single dynamic pressure measurement near 6 psi agrees well with ideal.

2.9.5 Summary

The over-all significance of UPSHOT-KNOTHOLE was to point out that thermal effects upon the blast wave could depress peak overpressures quite severely so that serious departures from the ideal could be expected for low burst heights depending on surface conditions. Furthermore, it was learned that height-of-burst curves for peak overpressures do not uniquely define all blast parameters in the nonideal region. It is considered that UPSHOT-KNOTHOLE substantiated the thermal layer concept for precursor generation. It should be noted, however, that nothing further was learned that would explain the results of BUSTER in so far as the extreme depressions of peak pressure from the ideal were observed for various burst heights on that operation.

It was also demonstrated in the nonideal region that dynamic pressures were not correspondingly depressed but could be larger than those calculated from ideal values of peak overpressures. It is considered that measured values of q as recorded during this operation included the effects of dust; however, the exact contribution of dust under such circumstances has not been completely determined. The dust pedestal actually extends to approximately one shock wave length beyond the range at which the precursor becomes extinct.

The usual characteristics of precursor formation and propagation were observed on Shots 1, 10, and 11, except that some deviations were noted on Shot 1. Shot 1 exhibited a steep rise in contrast to a more irregular wave form observed on Shots 10 and 11 and on TUMBLER 4. Shot 1 may be considered an anomaly in so far as more severe thermal effects were noted than on GREENHOUSE Dog and Easy, although the delivery of thermal radiation vs time was similar in

[redacted]

all three cases. It is considered that very little experimental data were obtained that would assist in developing criteria for predicting precursor formation and propagation.* However, UPSHOT-KNOTHOLE was successful in pointing out the need for further information on flow patterns behind the shock front in the nonideal region.

2.10 DAMAGE CRITERIA

2.10.1 Basic Considerations

In determining damage criteria to targets of military interest, the geometry of the burst is a significant factor. The difference between high and low burst heights is pointed up by thermal considerations which affect blast-wave parameters for low bursts. Such effects are superimposed upon normal geometric considerations with regard to the extent of the regular reflection region and the triple point. Consequently, the effective blast parameters used to predict damage are implicitly related to burst position and weapon size. However, the extent to which thermal influences on the blast wave are significant in realistic situations has not yet been completely determined. A factor which most probably contributed to the extensive damage on U-K Shot 10 was the relatively high flat-top pressure wave form in the precursor region with constant blast pressure and corresponding dynamic pressure over an extensive portion of the positive phase. In the case of drag-sensitive targets, results of U-K Shot 10 indicated that relatively low burst heights may be most favorable for optimum damage because of strong wind loadings due to burst geometry. A question naturally arises as to the contribution of dust loading in the nonideal region and the significance of the flow pattern under such circumstances.

2.10.2 Use of the Height-of-burst Curves

The entire philosophy of the height-of-burst peak pressure curves has been revised as a result of the unexpectedly high dynamic pressure observed on Shots 10 and 11 in the nonideal region. The results have produced essentially a sharp deviation in the nature of damage criteria required for various types of structures. The original intent of the height-of-burst curves was not to present peak pressure values that would cause damage but rather to indicate distance from Ground Zero at which particular degrees of damage occur. The height-of-burst curves were to be used in conjunction with an auxiliary table presenting the types of structures and the so-called "pressure" level at which light, moderate, or severe damage may result. The combination of the table and set of height-of-burst curves was intended to correlate the type of structure and the distance from Ground Zero at which the specified damage is estimated to take place. The actual pressure values were not intended to be the sole criteria of damage. It is believed that the UPSHOT-KNOTHOLE results do not significantly alter the foregoing philosophy in the case of pressure-sensitive targets. One main conclusion resulting from the UPSHOT-KNOTHOLE program appears to be that there is a need for an equivalent set of height-of-burst curves presenting dynamic pressures rather than static overpressure to be applied in problems involving drag-sensitive targets. For example, in the case of mobile tanks and trucks, the vertical components of the precursor pressure wave may tend to lift the targets off the ground and thereby convert them essentially into missiles. As a result of severe impact forces experienced upon landing, these missiles can suffer very significant damage. Dynamic pressures in the precursor region appear to be the most significant contributing factor to phenomena of this type. Another area where drag effects are important is in the case of parked aircraft, which are more sensitive to gust loading than static overpressure.

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*Following UPSHOT-KNOTHOLE, a series of tests (CASTLE) was held in the Pacific. It is considered that the results of these tests, for weapons ranging from 100 KT to 15 MT bursts at the surface over an essentially ideal reflecting plane, gave results consistent with predictions according to conventional scaling of blast-wave parameters. No significant thermal effects on the blast wave were observed during these tests, although nonideal wave forms were observed as well as possible water loading of the shock wave.

[redacted]

Since measured pressure varies with height above ground, the nature of the height-of-burst curves is governed by the choice of the data to be used. On the basis of the intended purpose of the height-of-burst curves, it appears satisfactory to use surface-level measurements, since the height-of-burst curves are used only as an arbitrary intermediate frame of reference to associate structures with areas of damage. One important factor that must be considered in the use of burst curves is the orientation of the structure with respect to the direction of blast loading. It is quite probable that a 10-psi pressure wave striking normally against the side of a structure will result in significantly different damage than a similar wave impinging on the roof of the same structure. This question can possibly be resolved by a study of the characteristics of response to blast loading for individual types of structures, and some modifying parameter can be used in problems where these structures are being considered. It is believed that the fundamental purpose of the height-of-burst curves is to give design engineers some reasonable estimates of the nature of the blast loads that will occur in various areas due to a nuclear blast.

2.11 RECOMMENDATIONS FOR FUTURE TESTS

As a result of UPSHOT-KNOTHOLE, it is now possible to define more clearly the areas of uncertainty in basic blast phenomena. It is considered that one of the primary deficiencies in the state of knowledge relates to the effects of thermal radiation on real surfaces and formation of the thermal layer. Indeed, the semiempirical criteria for precursor prediction apply largely to test surfaces such as desert, sand, and coral. Even for these surfaces, however, details of the preshock sound velocity or the mechanism of heat transfer necessary for a thermal gradient have not been established. Consequently, it is difficult to extrapolate full-scale test results to real surfaces of military interest, such as forest, vegetated areas, and cities, in order to determine their relative influence on the blast wave as a result of thermal irradiation. Since it is apparent that surface dust effects on UPSHOT-KNOTHOLE were significant in so far as measured values of dynamic pressure are concerned, an attempt should be made to investigate the precursor in the absence of dust to determine the various relations between the parameters. It is therefore recommended that a full-scale test be held at a low burst height for purposes of measuring the free field blast parameters over the representative surfaces discussed in Sec. 2.4.3.6, which were described as ideal, desert, and organic. In this way departures in blast behavior from the ideal could be observed for both a dust and nondusty precursor. These measurements should include overpressure and dynamic pressure vs time as a function of ground range and height above the ground on all three blast lines. In addition, an attempt should be made to measure such quantities as particle velocity, air and dust density, direction of particle motion, temperature, and preshock sound velocity at various stations to correlate with p and q measurements.

Another unresolved question relates to blast-wave characteristics and damage in the nonideal region for a low precursor-forming burst, as compared to that which would be obtained in the same high-intensity blast region for an ideal burst. It is therefore recommended that a medium yield land surface burst be fired, preferably over a dusty region. This event would provide information as to the relative contribution of dust to the effects of blast in the strong shock region as well as to determine the significance of the additional dust loading as the result of the precursor. Such a test would also provide valuable data on cratering and ground shock as well as thermal and nuclear radiation.

As noted above there is very little test information in the ideal region for blast waves having an intensity corresponding to those observed on UPSHOT-KNOTHOLE in the nonideal case. It is considered that a low air burst over an ideal surface would provide such information. In order to avoid interaction of the fireball with the surface, a true air burst should be employed with an A-scaled height of burst equal to or greater than 1.5 fireball radius. It is therefore recommended that a high-yield air burst in the megaton range be fired to provide basic air blast data in the ideal case for low bursts as well as to confirm scaling under such blast conditions.

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In order to resolve present differences in prediction criteria for precursor formation, it is recommended that blast measurements be made for a 1 to 2 KT burst fired at an A-scaled height between 50 and 450 ft. A development shot on a tower would be satisfactory for such purposes.*

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*This report was written prior to the TEAPOT test series at the NPG.

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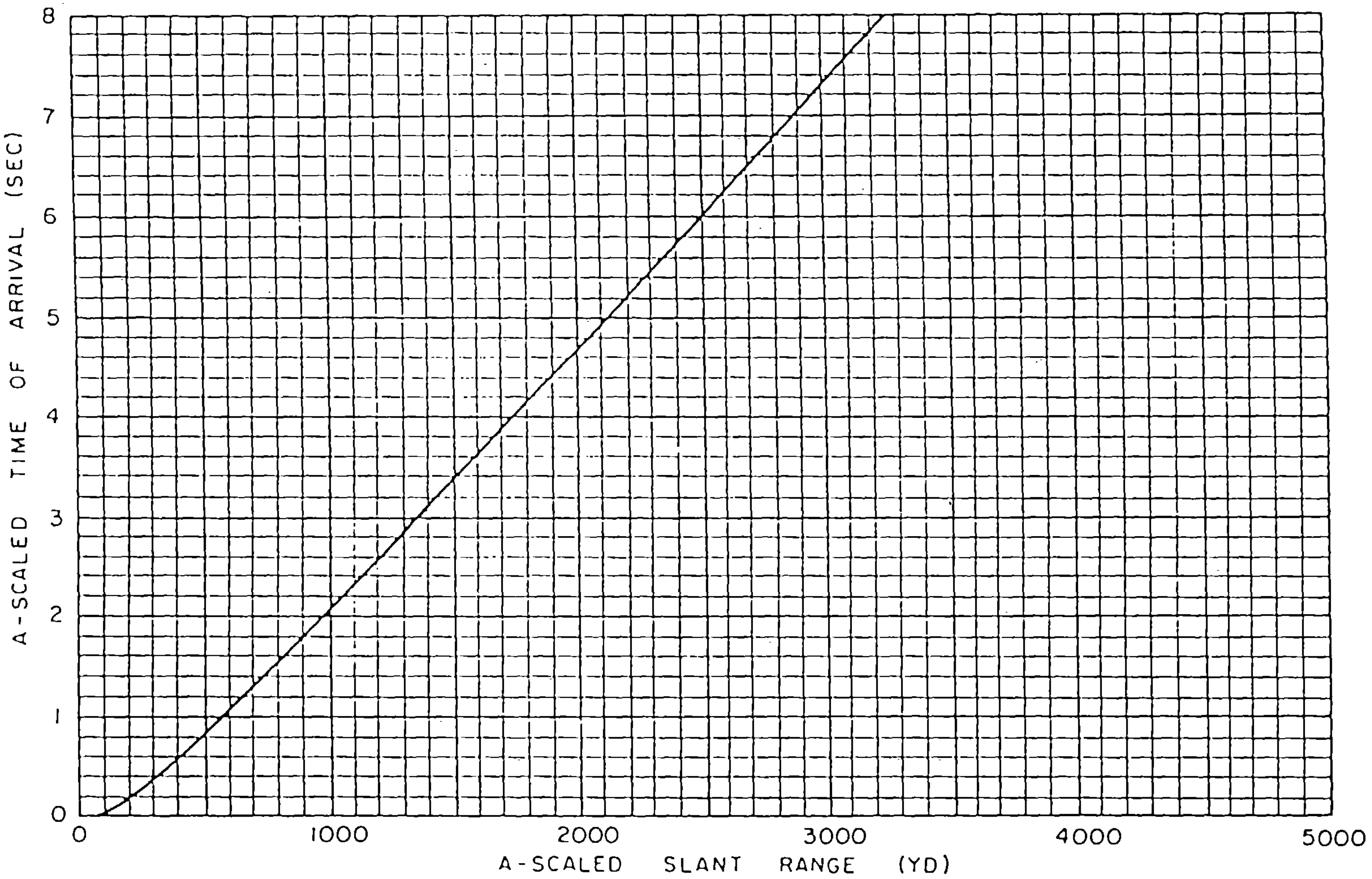

Fig. 2.1—Composite UPSHOT-KNOTHOLE-TUMBLER-IVY Time-of-arrival Curve.

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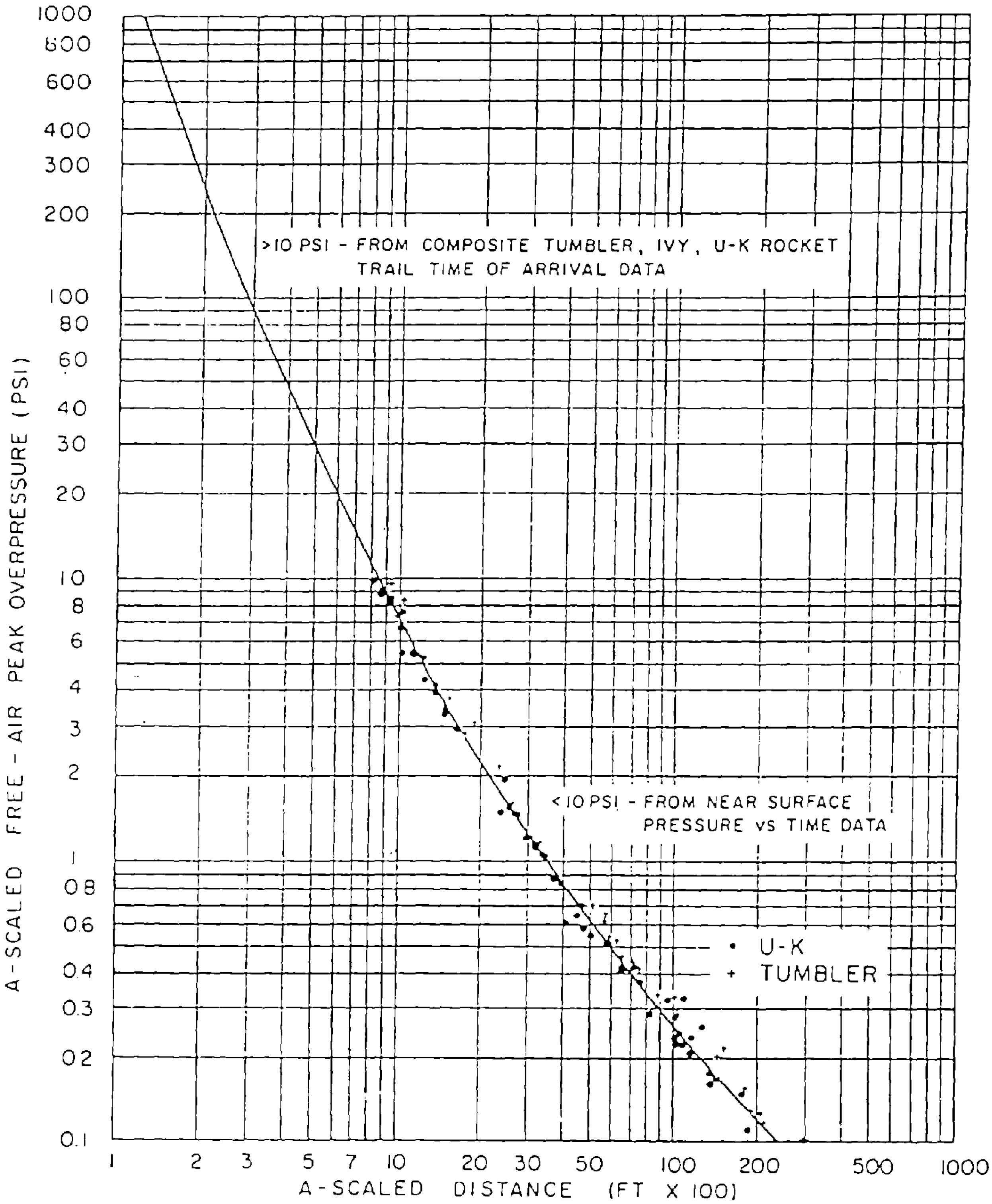

Fig. 2.2—Proposed Standard Free Air Peak Overpressure Curve.

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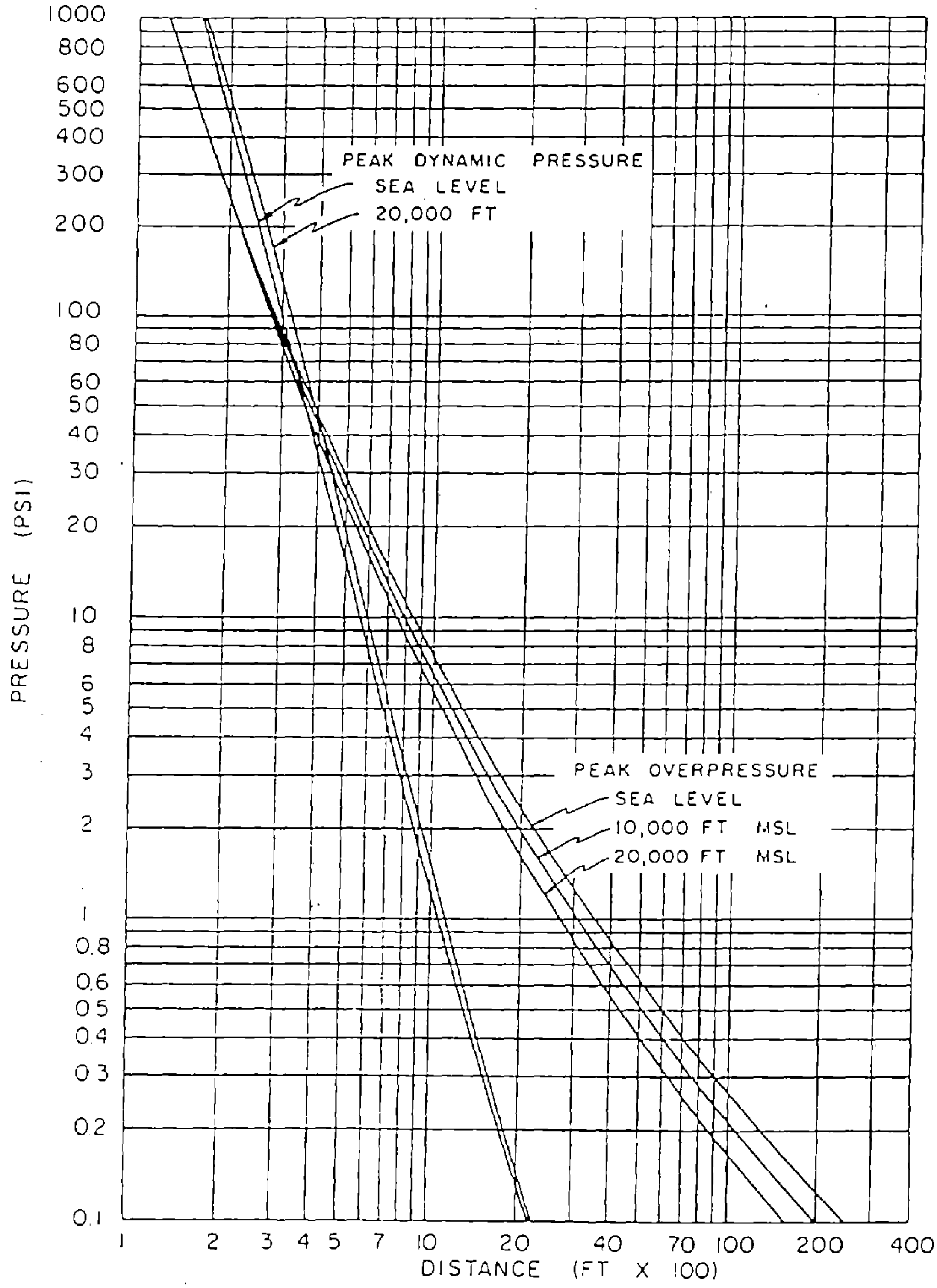

Fig. 2.3—Free Air Peak Overpressure and Peak Dynamic Pressure for Various Altitudes.

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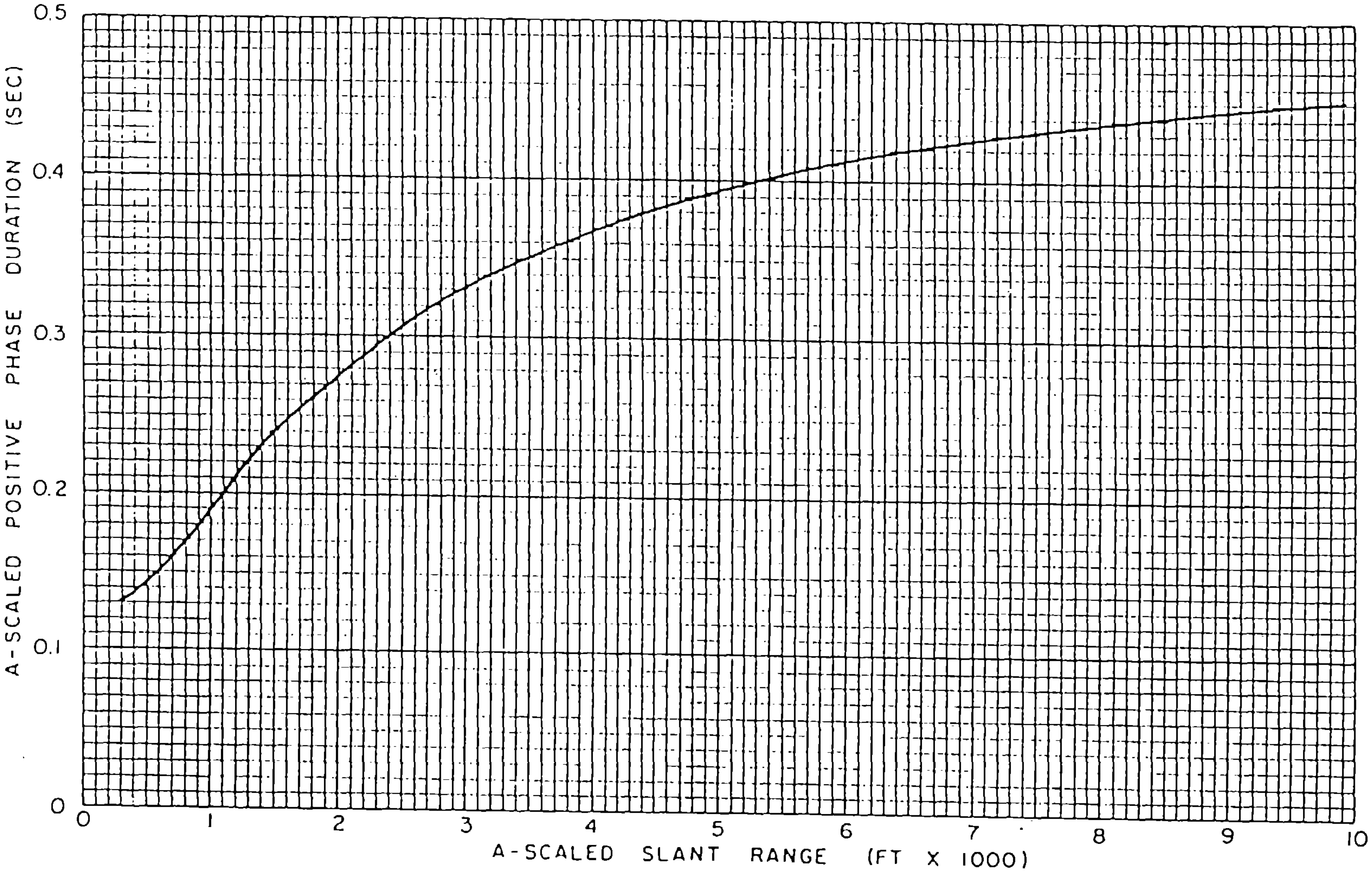

Fig. 2.4—Free Air Overpressure Positive Phase Duration (A-Scaled).

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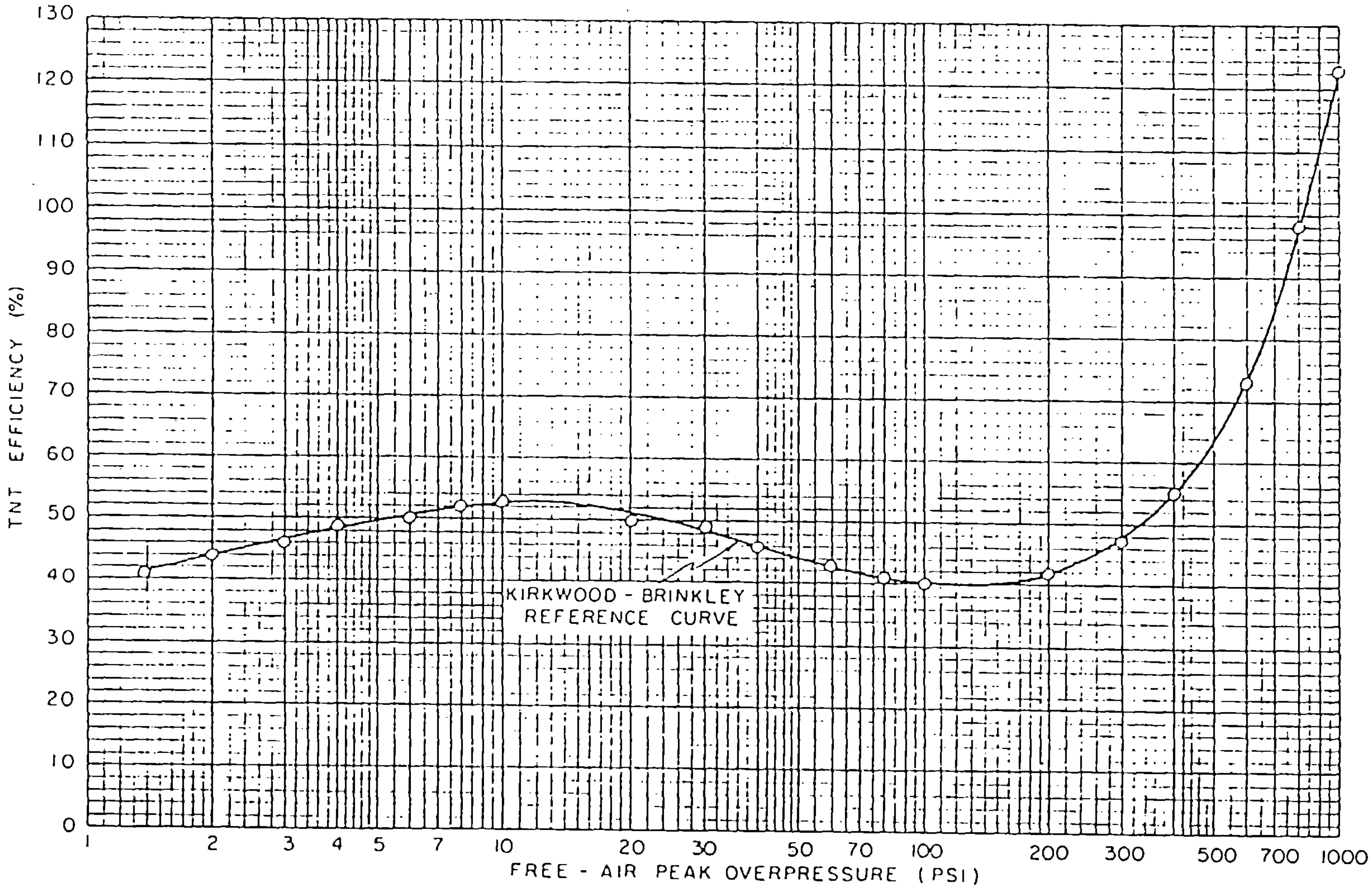

Fig. 2.5—TNT Efficiency Vs Free Air Peak Overpressure, Using Kirkwood-Brinkley Reference Curve for TNT.

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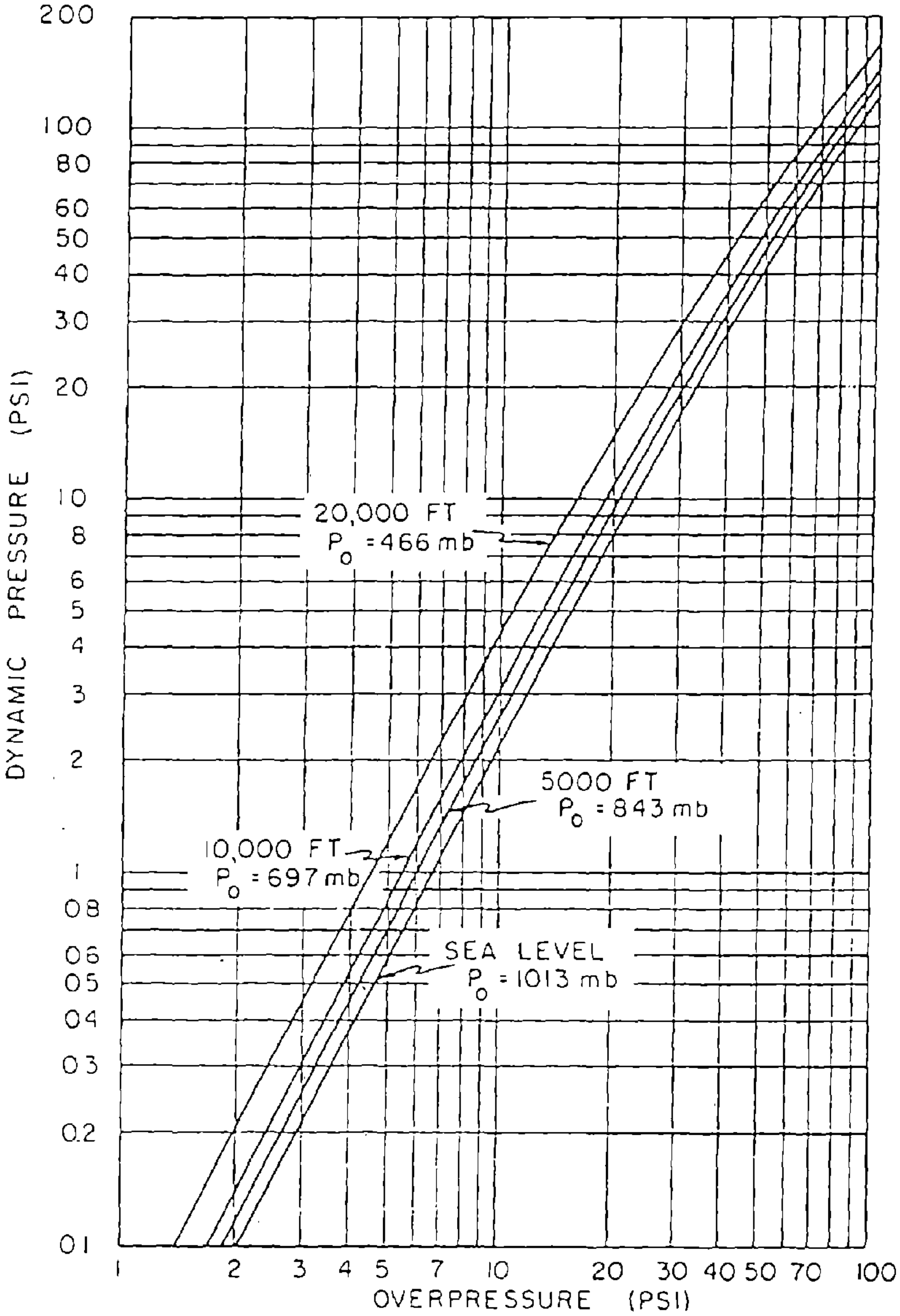

Fig. 2.6—Free Air Peak Dynamic Pressure Vs Free Air Peak Overpressure for Various Altitudes.

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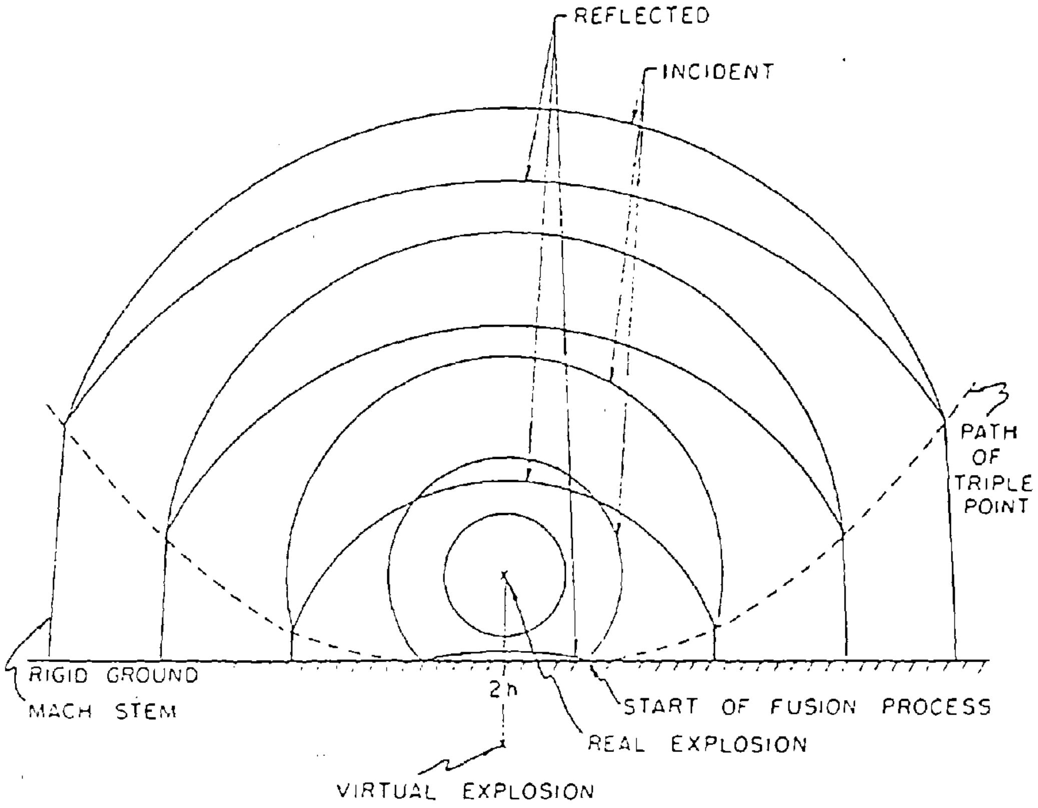

Fig. 2.7 — Schematic Drawing of Ideal Regular and Mach Reflection.

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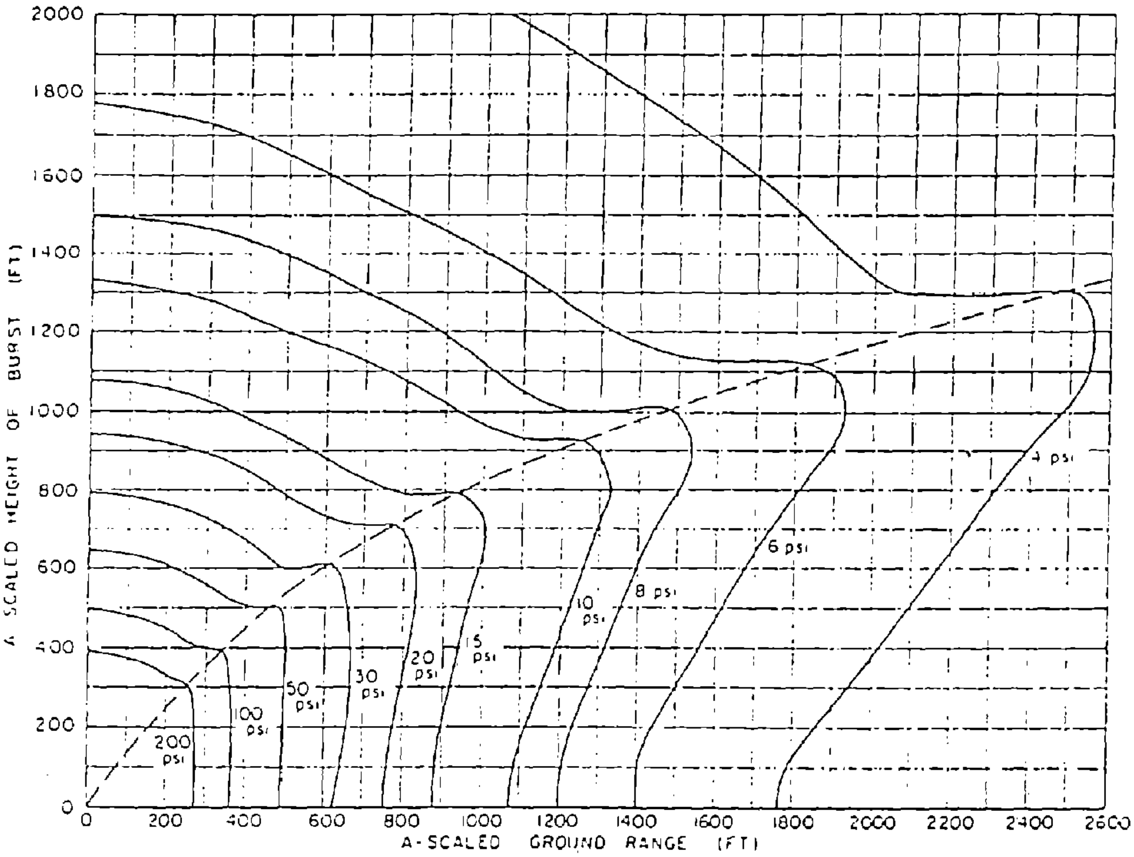

Fig. 2.8 — Ideal Peak Overpressure Height-of-burst Curves.

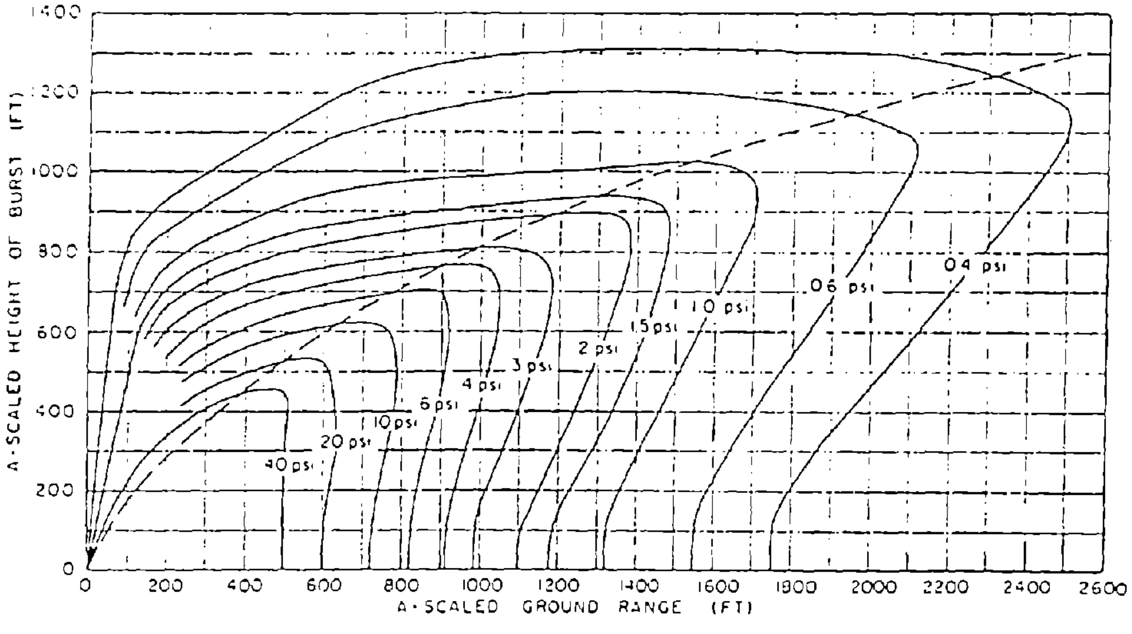

Fig. 2.9 — Ideal Peak Dynamic Pressure Height-of-burst Curves.

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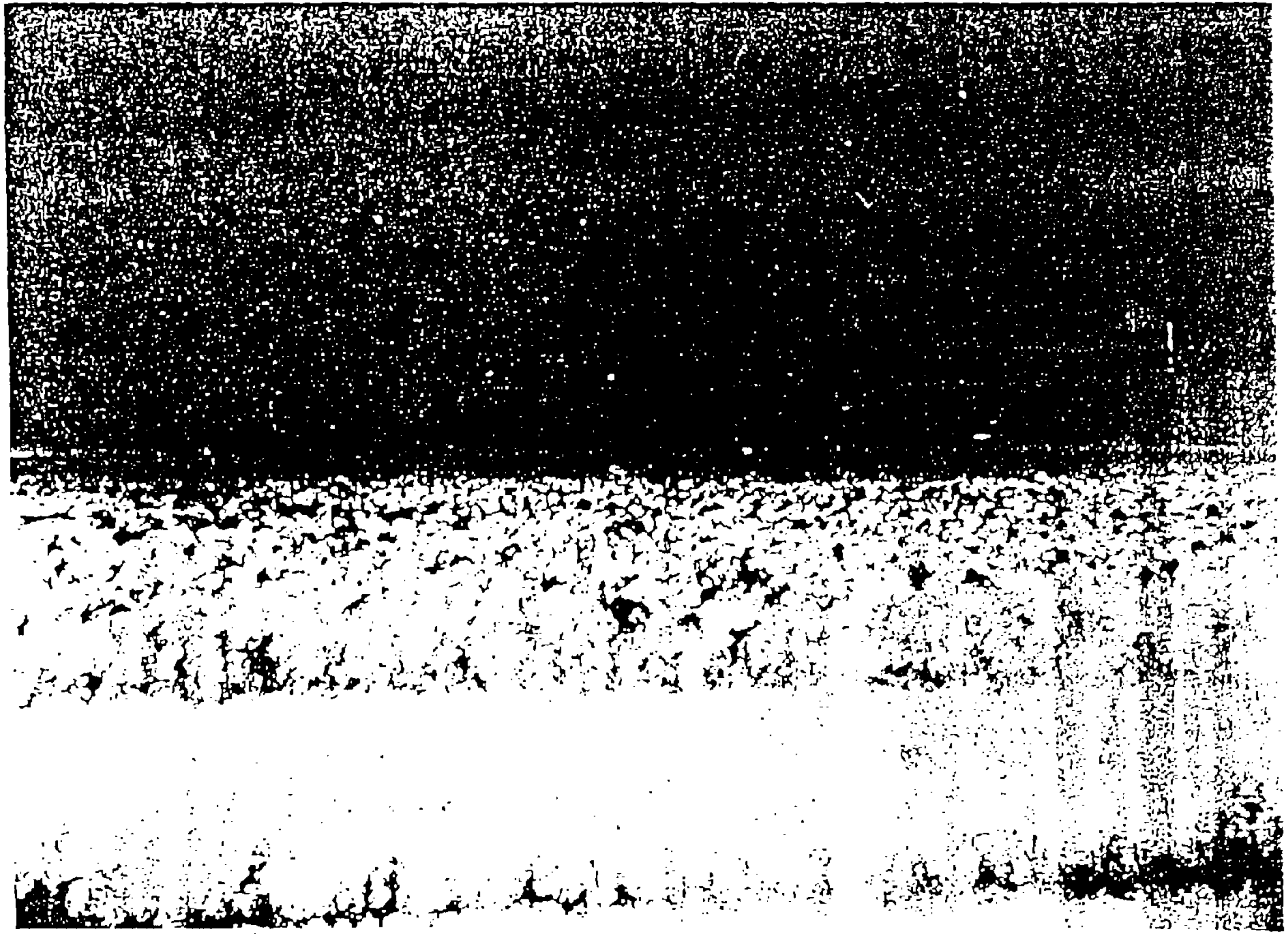

Fig. 2.10 — Photograph of Preshock Popcorning, Operation TUMBLER-SNAPPER.

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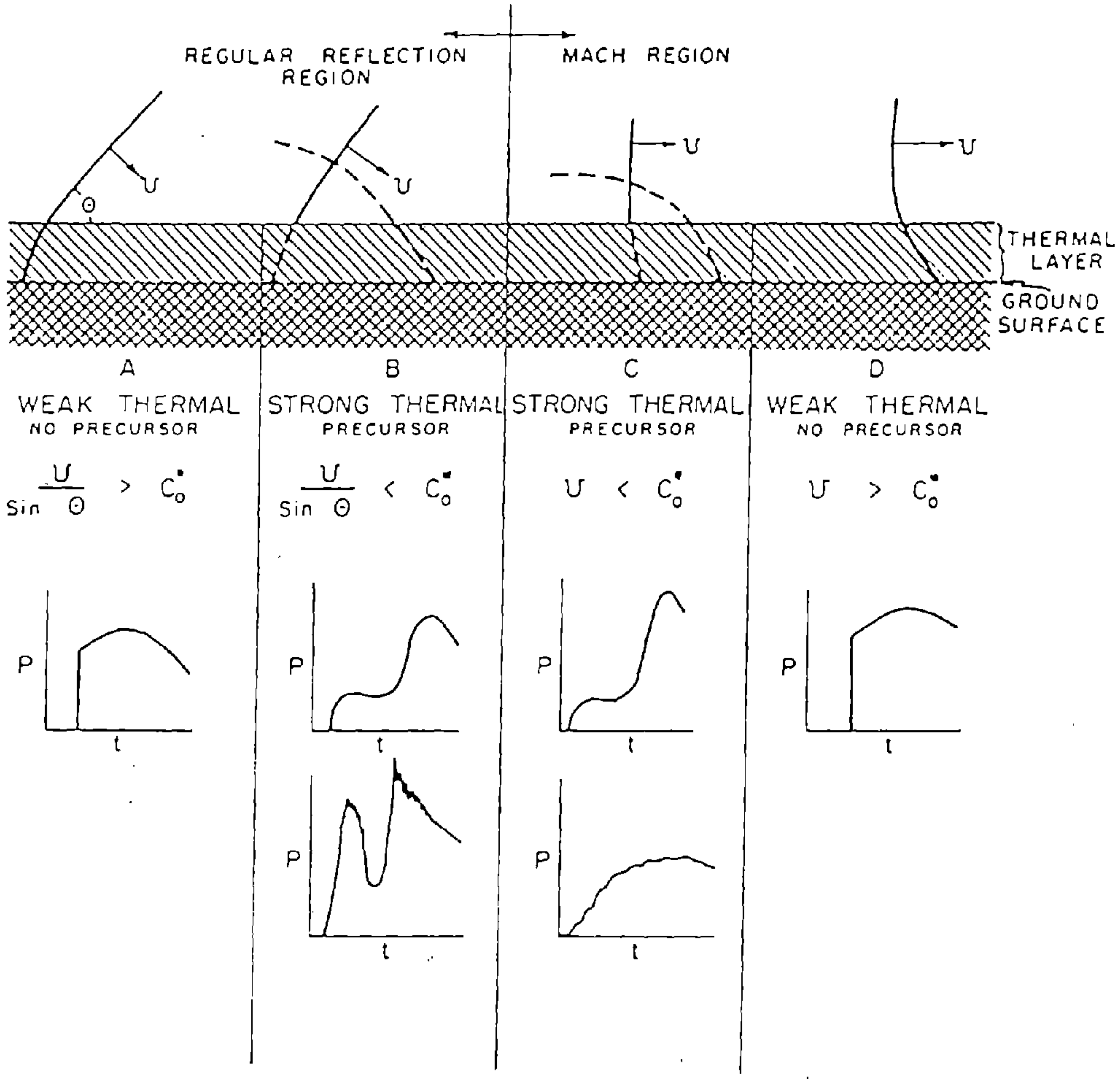

U - VELOCITY OF SHOCK TRANSMISSION IN UNHEATED AIR ABOVE THERMAL LAYER

C_o^* - VELOCITY OF SOUND IN THERMAL LAYER - A FUNCTION OF HEIGHT, GROUND RANGE AND TIME

(ALL REFLECTED SHOCKS OMITTED FOR SIMPLIFICATION)

Fig. 2.11—Schematic Diagrams of Precursor Formation.

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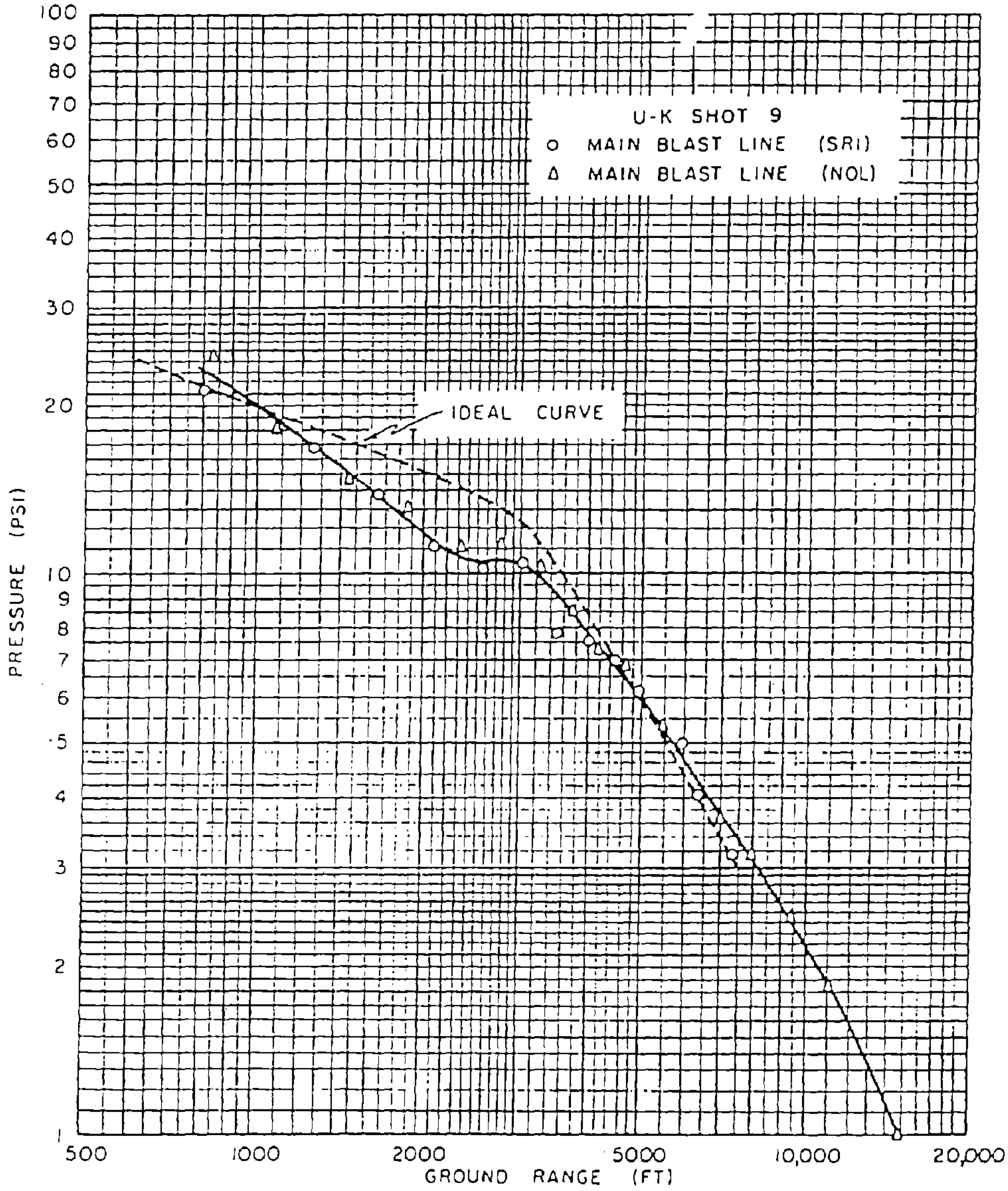

Fig. 2.12 — Ground-level Peak Overpressure, Shot 9, with Ideal Curve.

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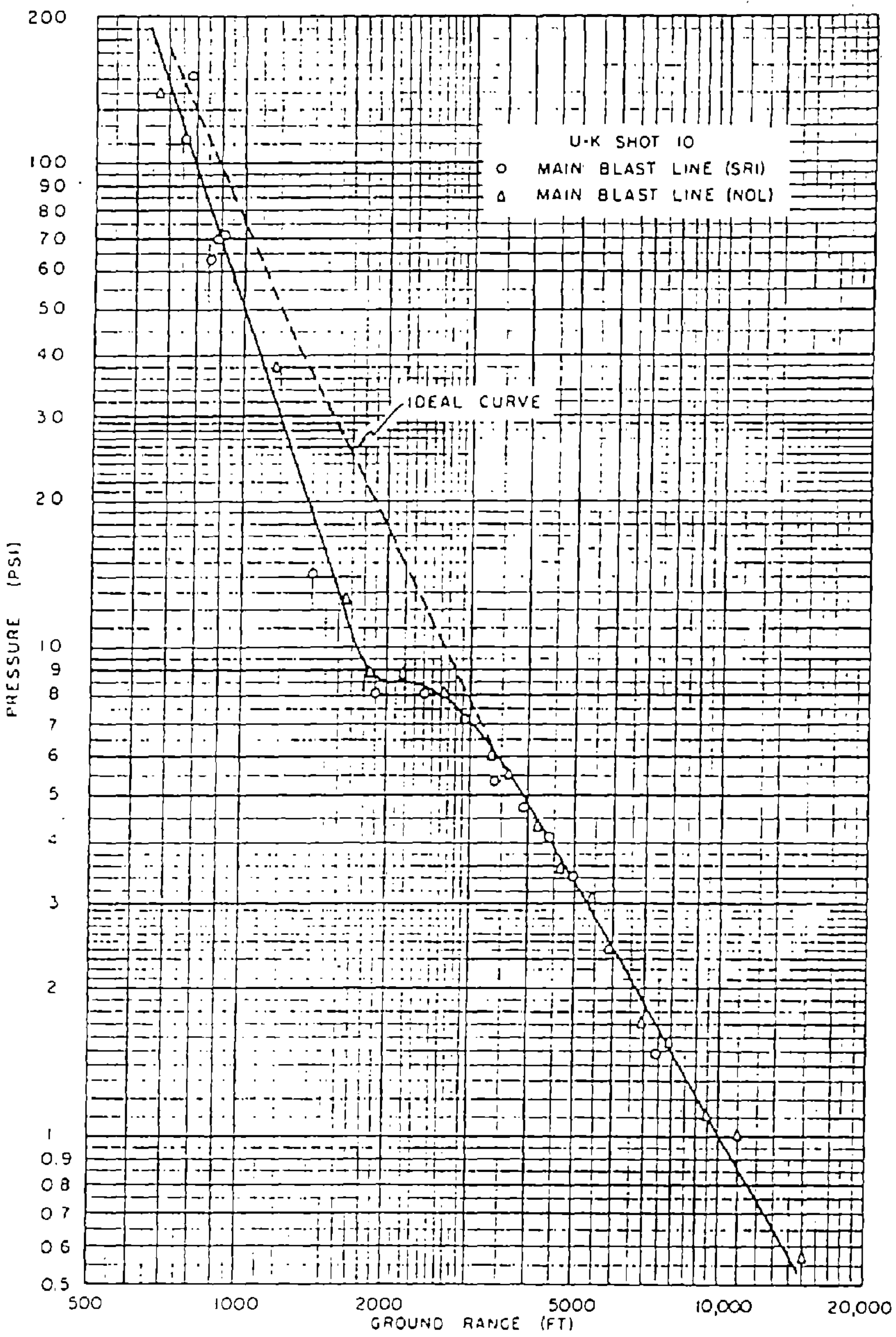

Fig. 2.13—Ground-level Peak Overpressure, Shot 10, with Ideal Curve.

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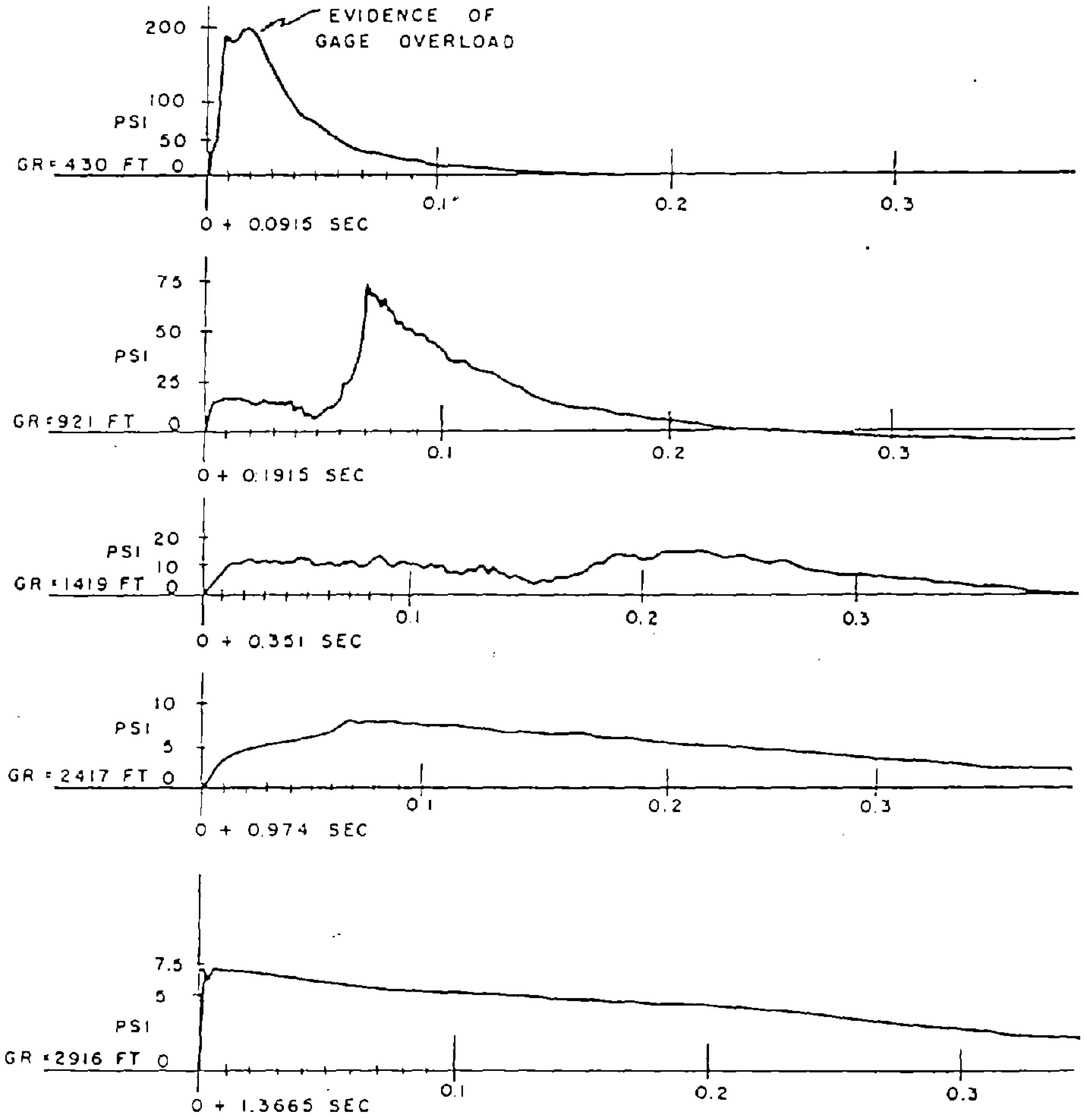

Fig. 2.14—Sample Shot 10 Ground-level Overpressure Vs Time Records in Nonideal Region.

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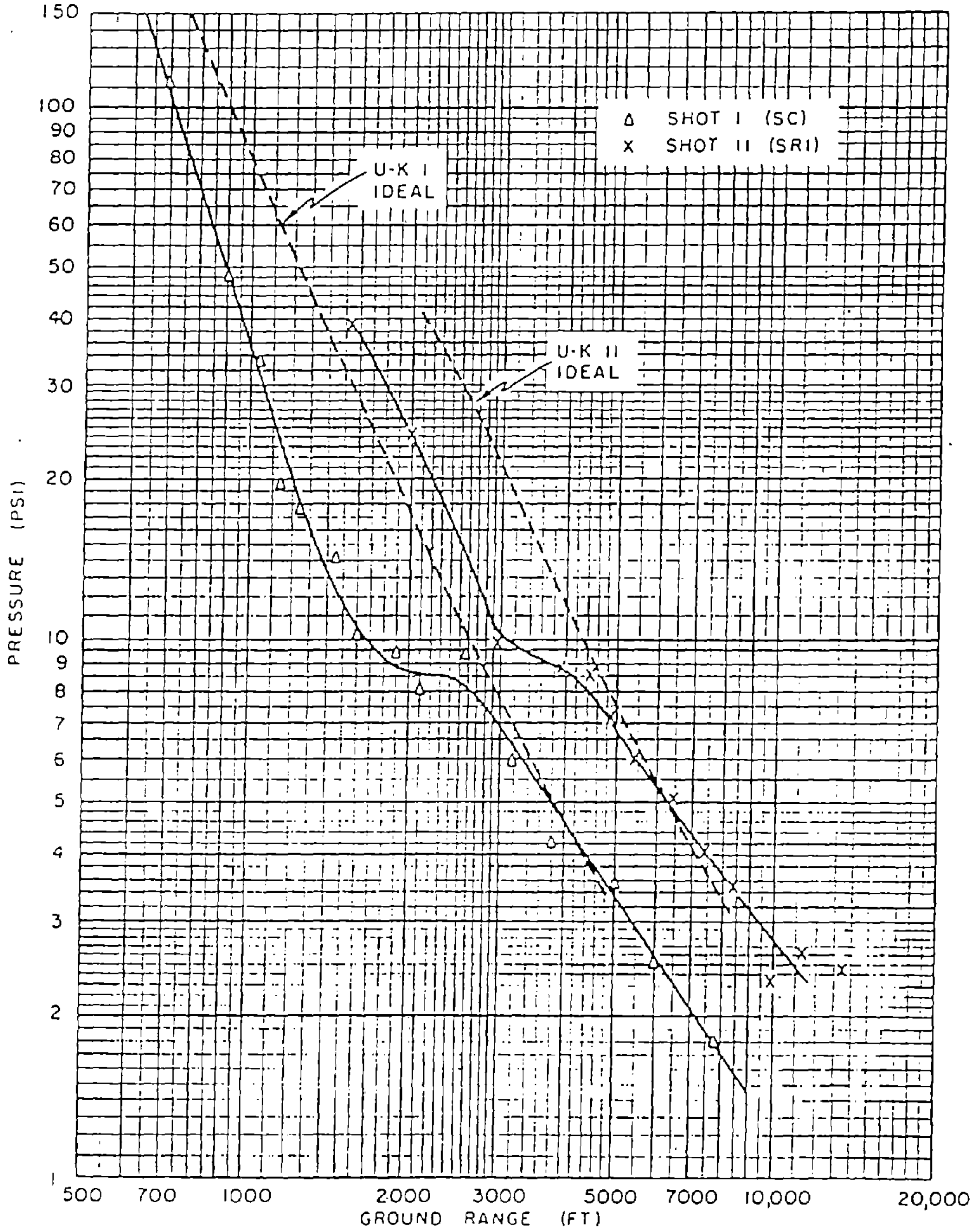

Fig. 2.15 — Ground-level Peak Overpressure, Shots I and II, with Ideal Curves.

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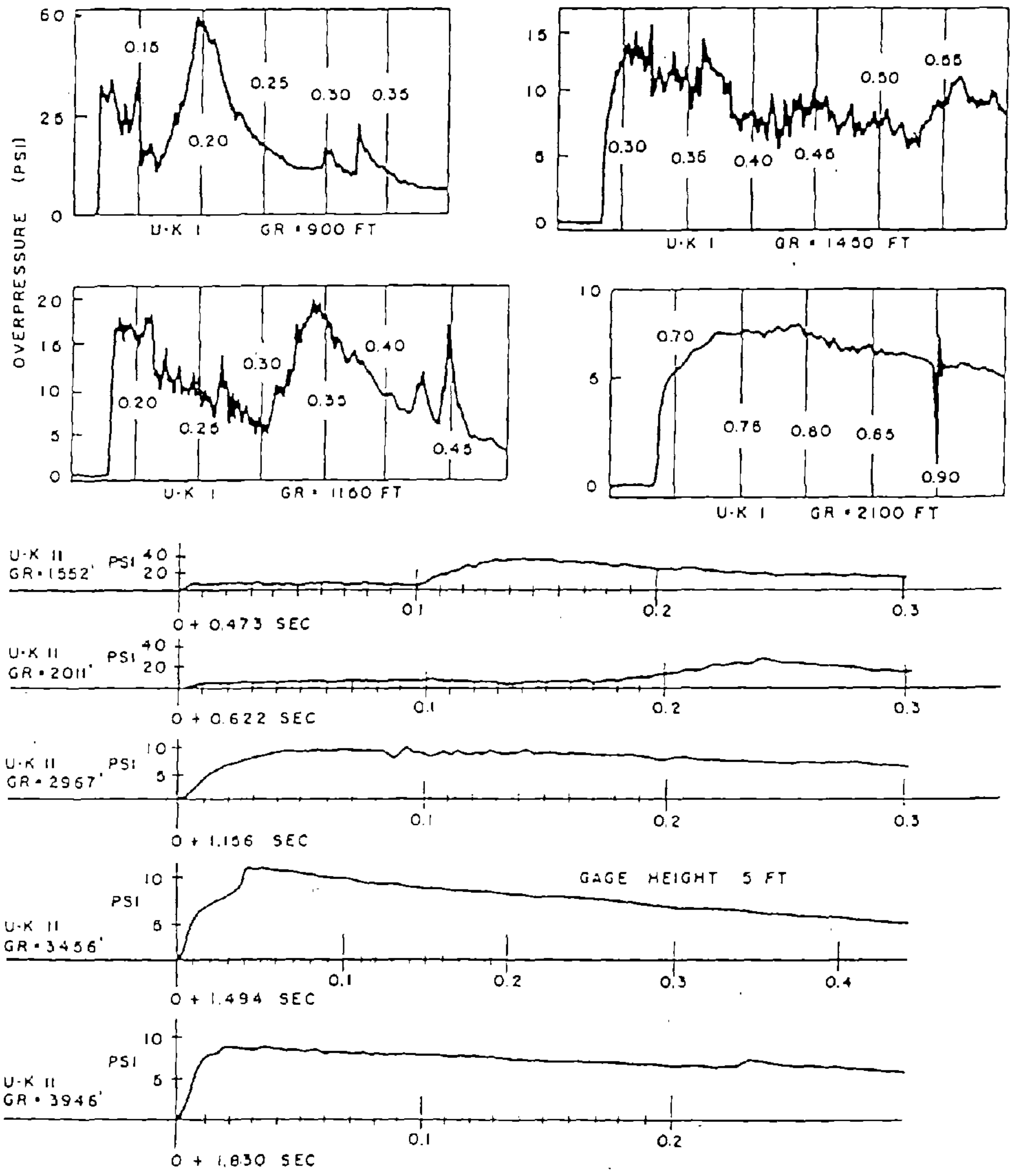

Fig. 2.16—Sample Shot I and Shot II Ground-level Overpressure Vs Time Records in Nonideal Region.

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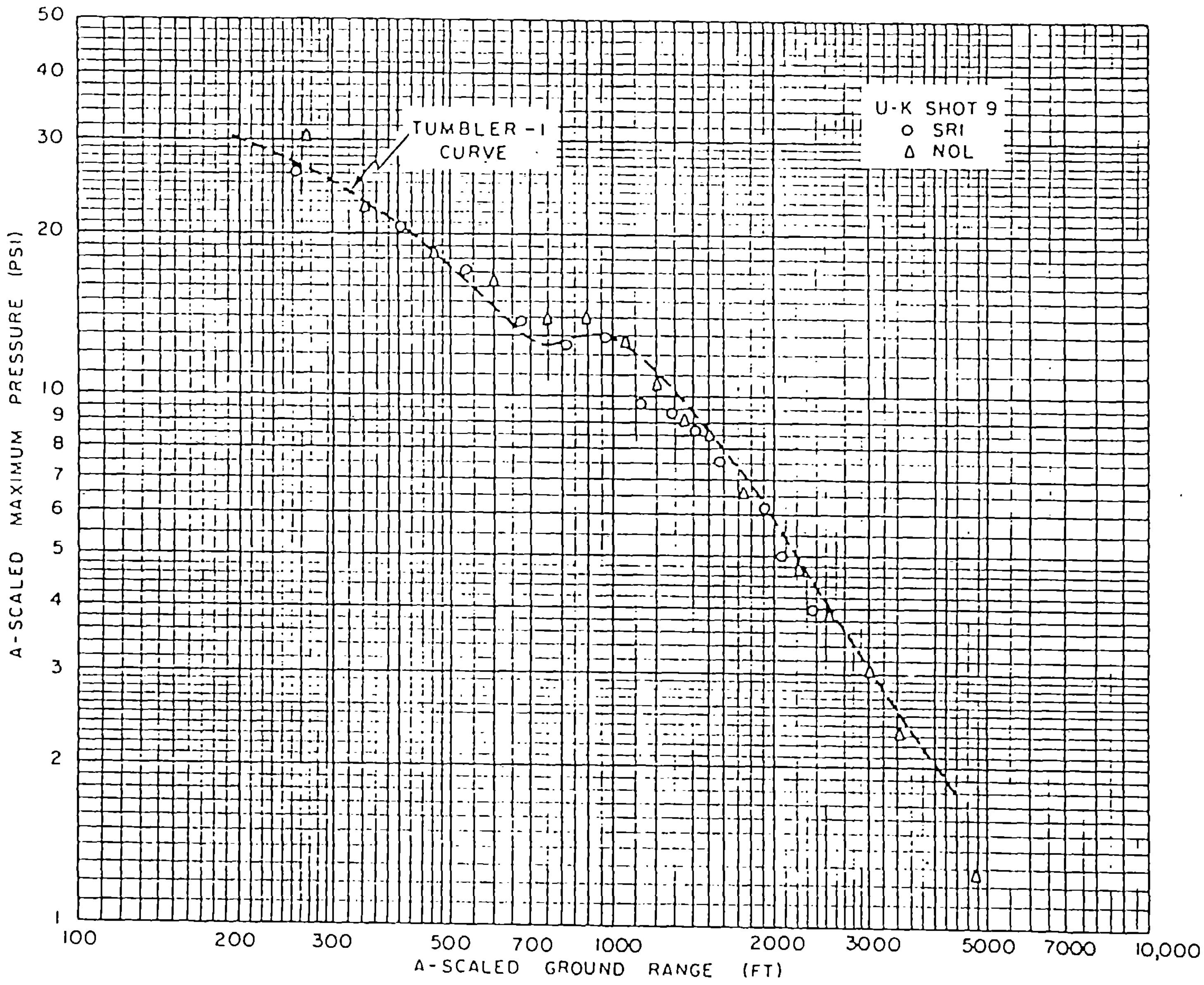

Fig. 2.17 — Shot 9 and TUMBLER Shot 1 Ground-level Peak Overpressure.

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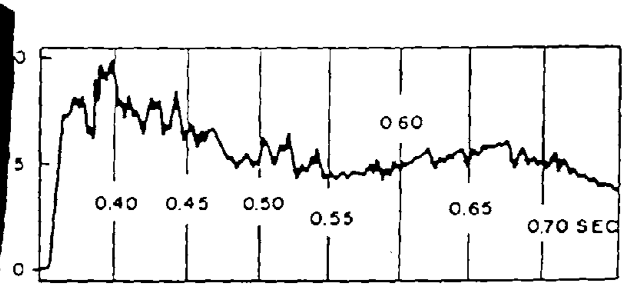

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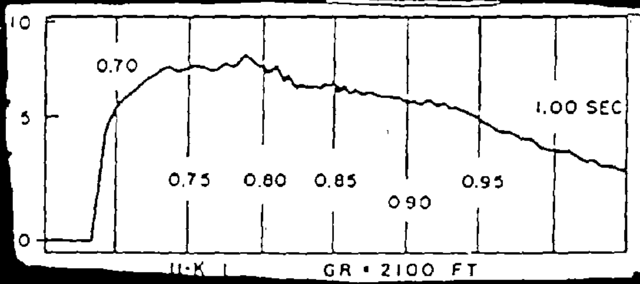

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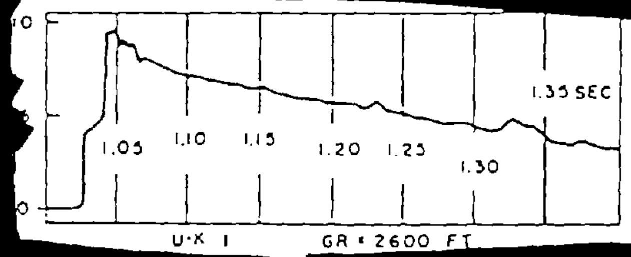

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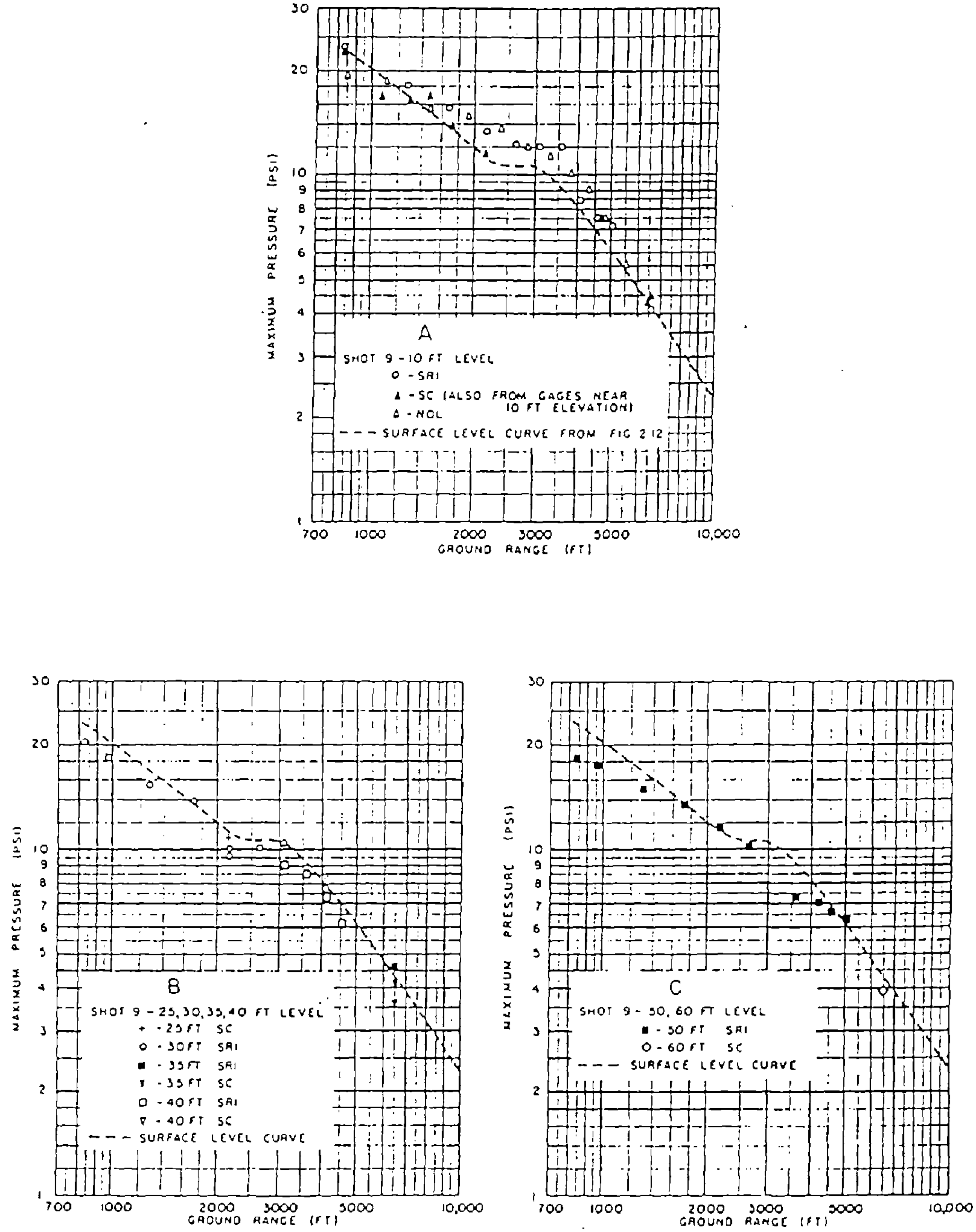

Fig. 2.20—Shot 9 Aboveground Peak Overpressure.

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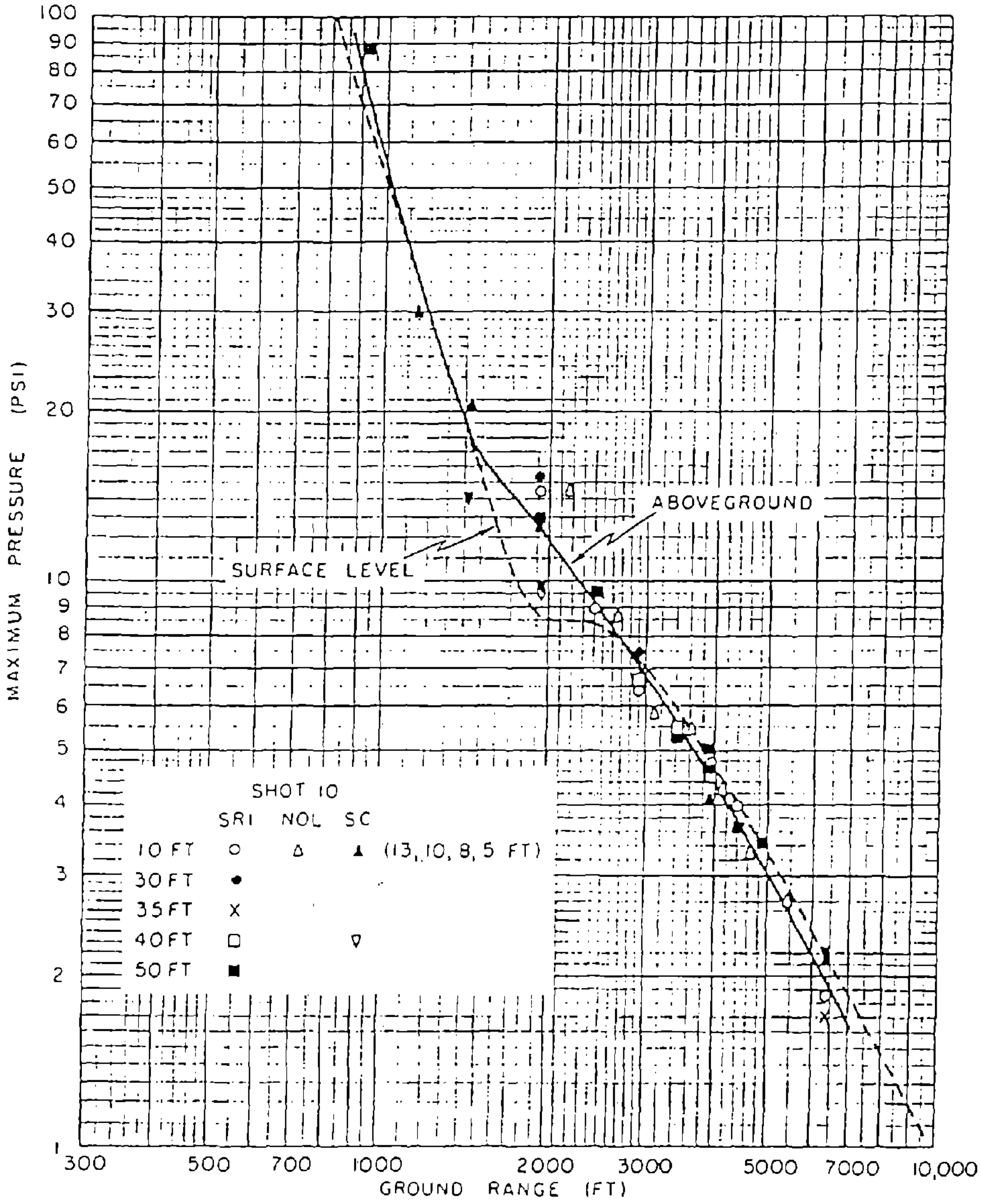

Fig. 2.21 — Shot 10 Aboveground Peak Overpressure.

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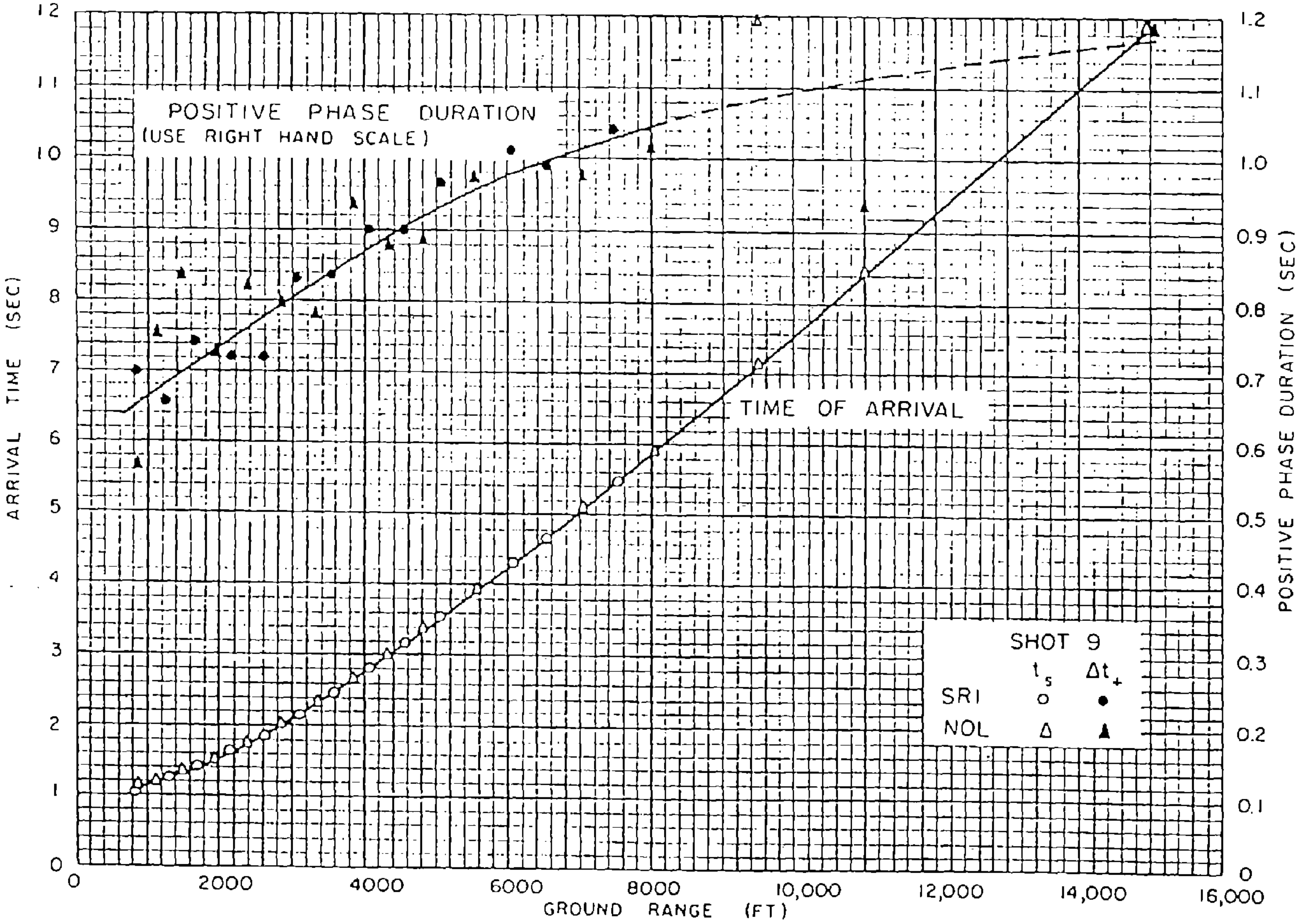

Fig. 2.24 — Positive Phase Duration and Arrival Time, Shot 9.

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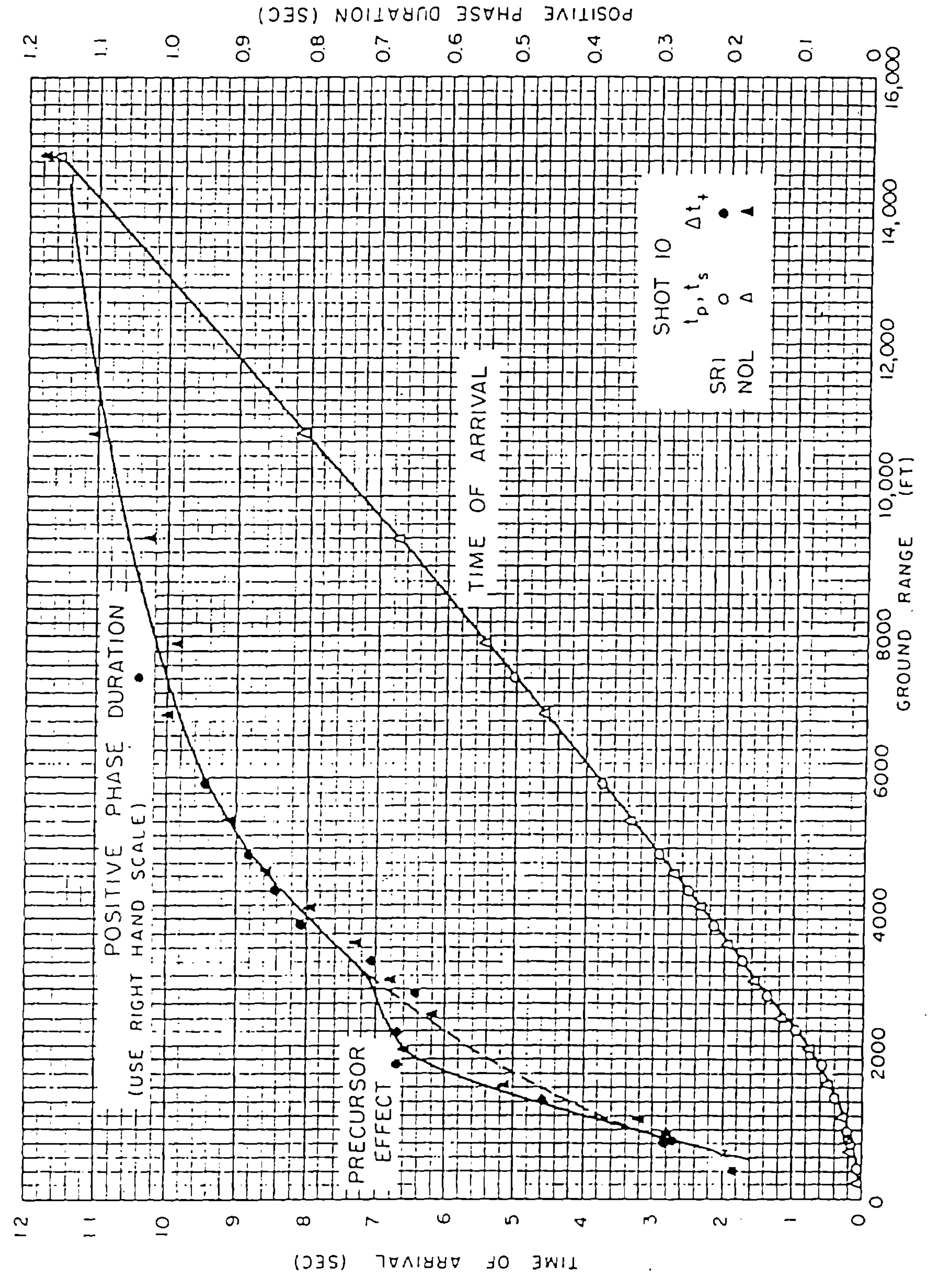

Fig. 2.25 — Positive Phase Duration and Arrival Time, Shot 10.

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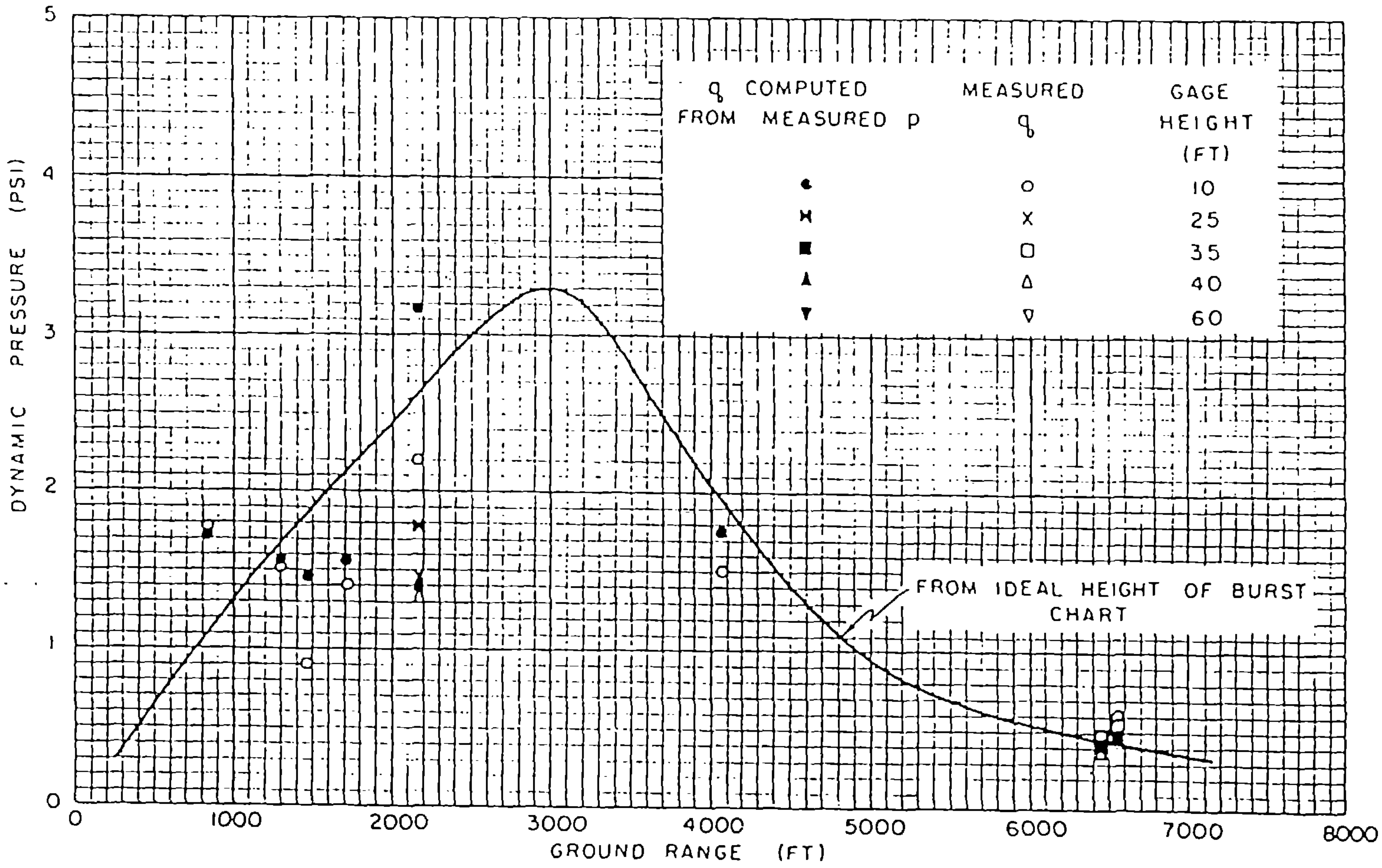

Fig. 2.26—Measured Dynamic Pressure, Shot 9, Compared to Ideal and to Dynamic Pressure Computed from Measured Peak Overpressure.

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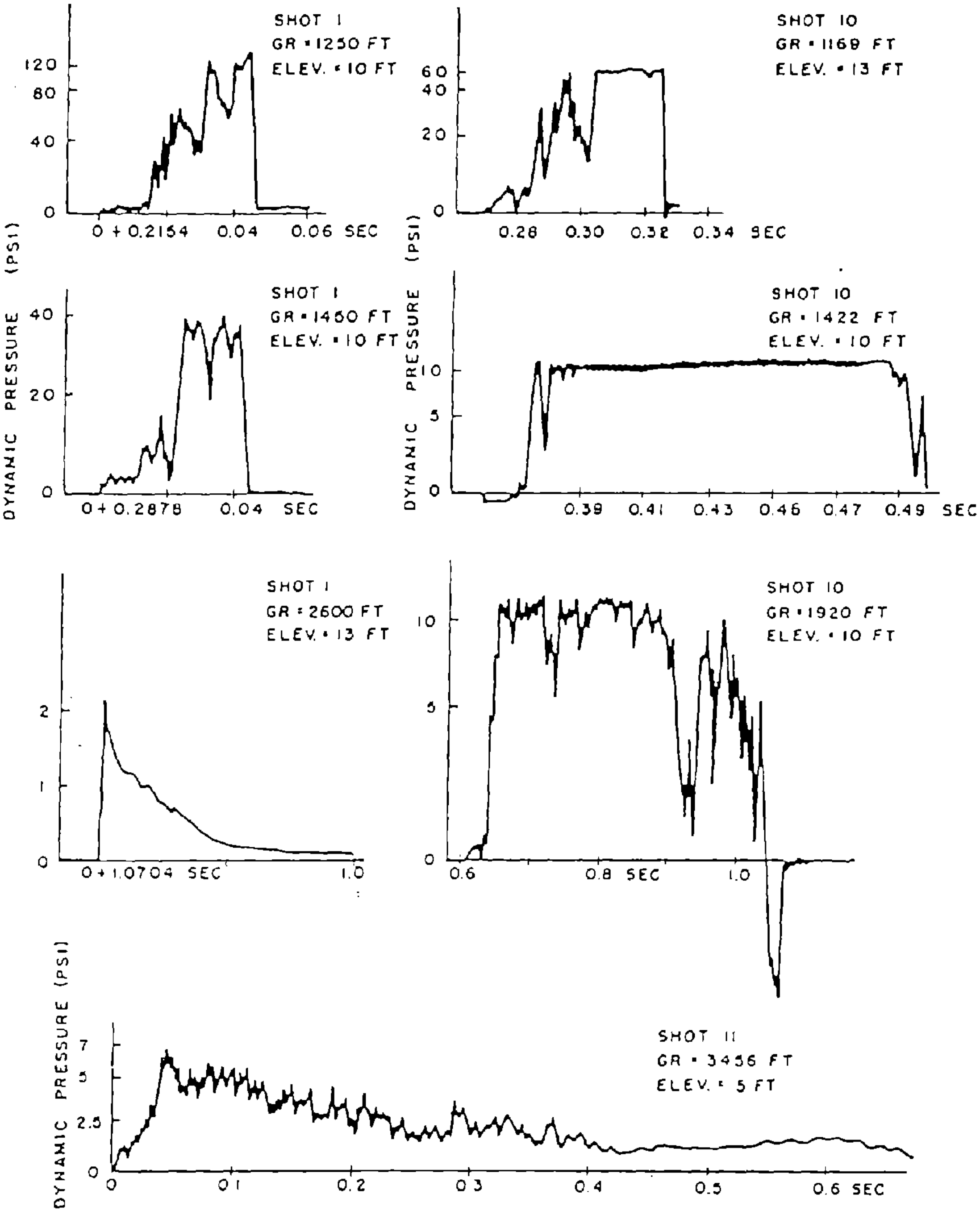

Fig. 2.27—Sample Dynamic Pressure Vs Time Records, Shots 1, 10, and 11.

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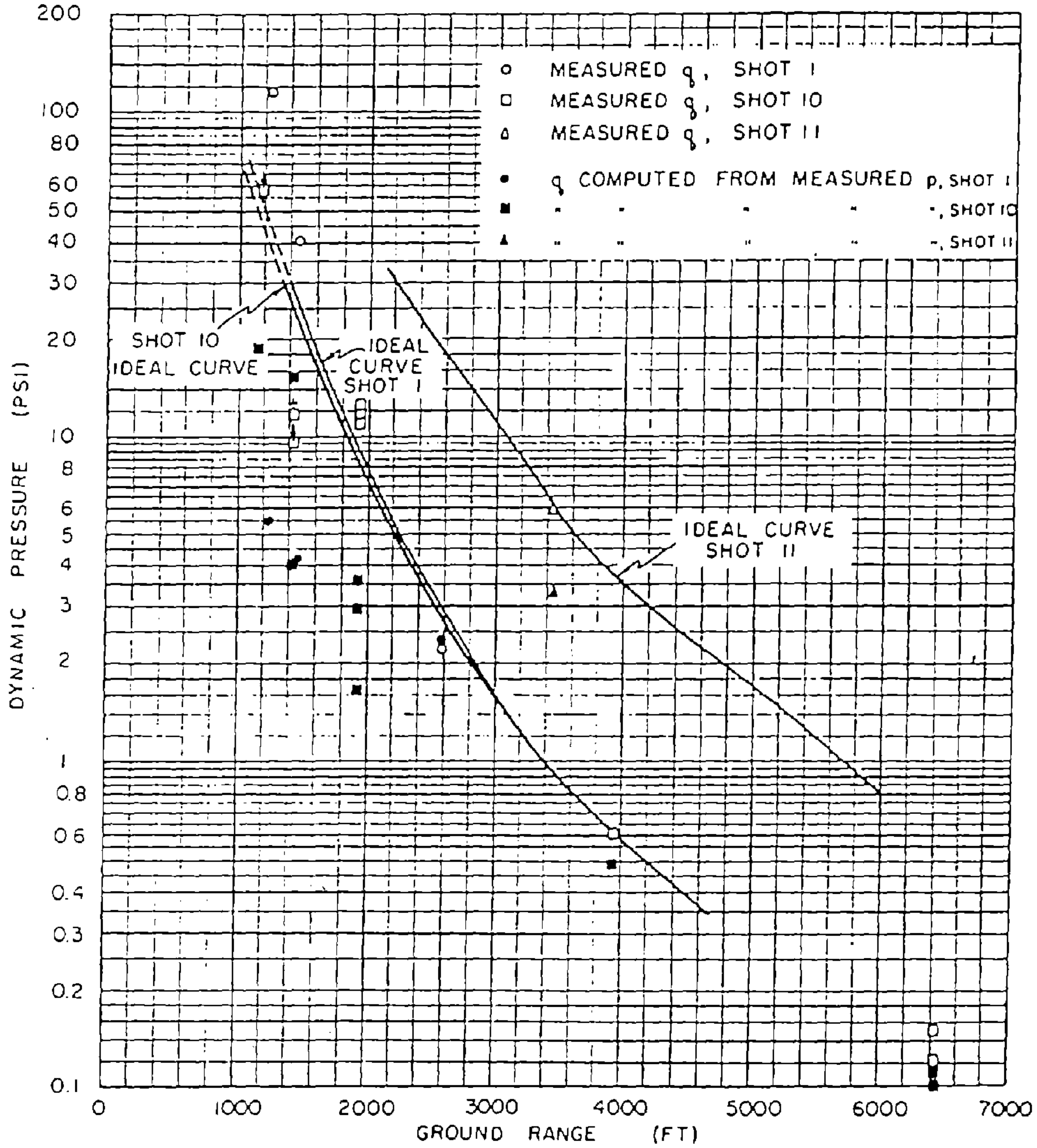

Fig. 2.28—Measured Dynamic Pressure, Shots 1, 10, and 11, Compared to Ideal and to Dynamic Pressure Computed from Measured Peak Overpressure.

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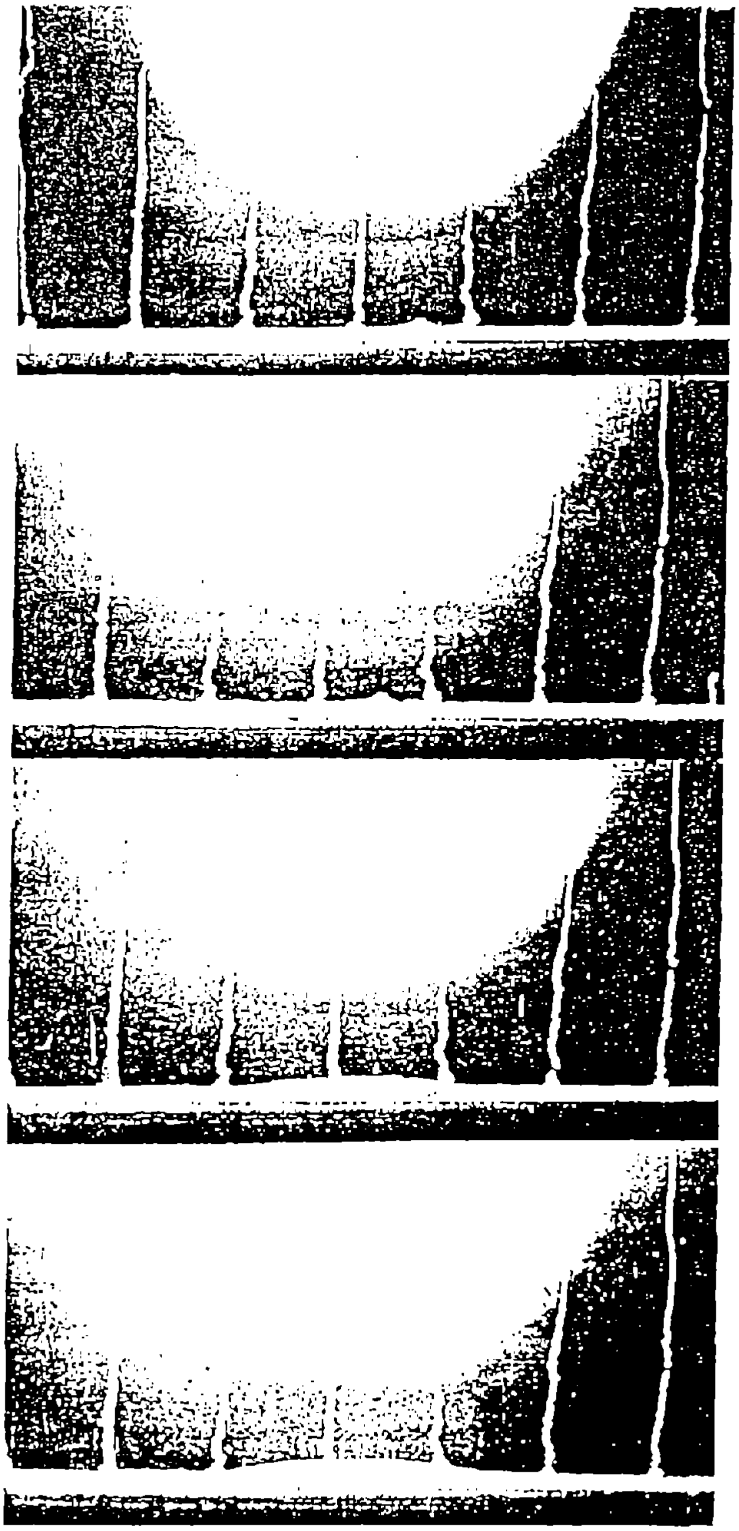

Approx. 0.22 sec after detonation. Just prior to incident wave striking Ground Zero.

Approx. 0.25 sec after detonation. Incident wave striking Ground Zero.

Approx. 0.28 sec after detonation. Appearance of reflected wave.

Approx. 0.29 sec after detonation. Development of reflected wave.

Fig. 2.29 — Precursor Development, Shot 11.

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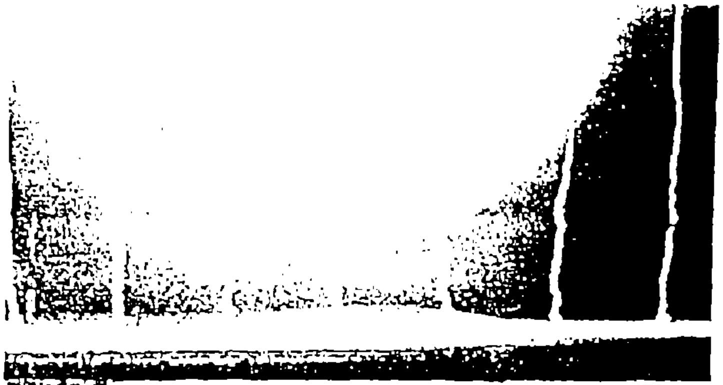
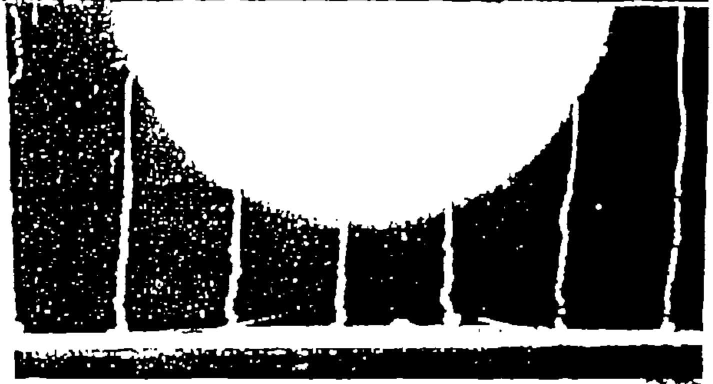
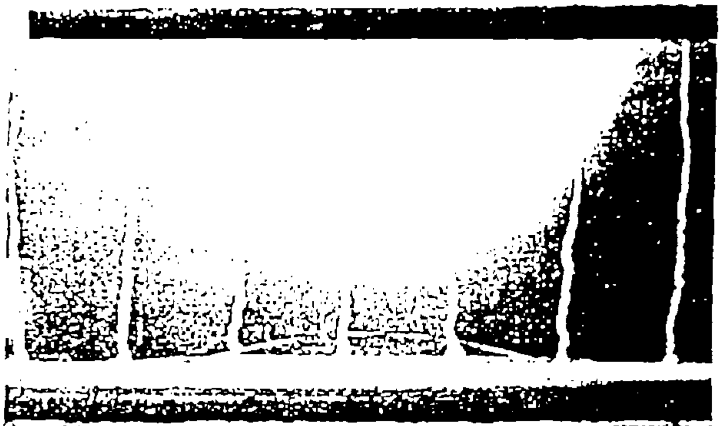
Approx. 0.30 sec after detonation. Further development of reflected wave—no evidence of precursor within resolution limits of photograph.



Approx. 0.31 sec after detonation. First evidence of precursor in advance of reflected wave at ground level.



Approx. 0.32 sec after detonation. Development of precursor.



Approx. 0.33 sec after detonation. Further development of precursor.

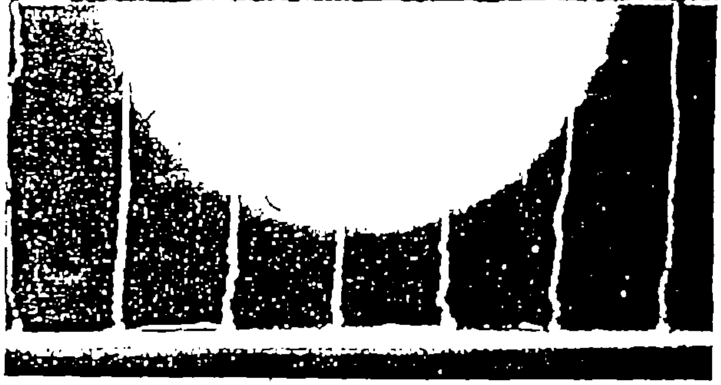
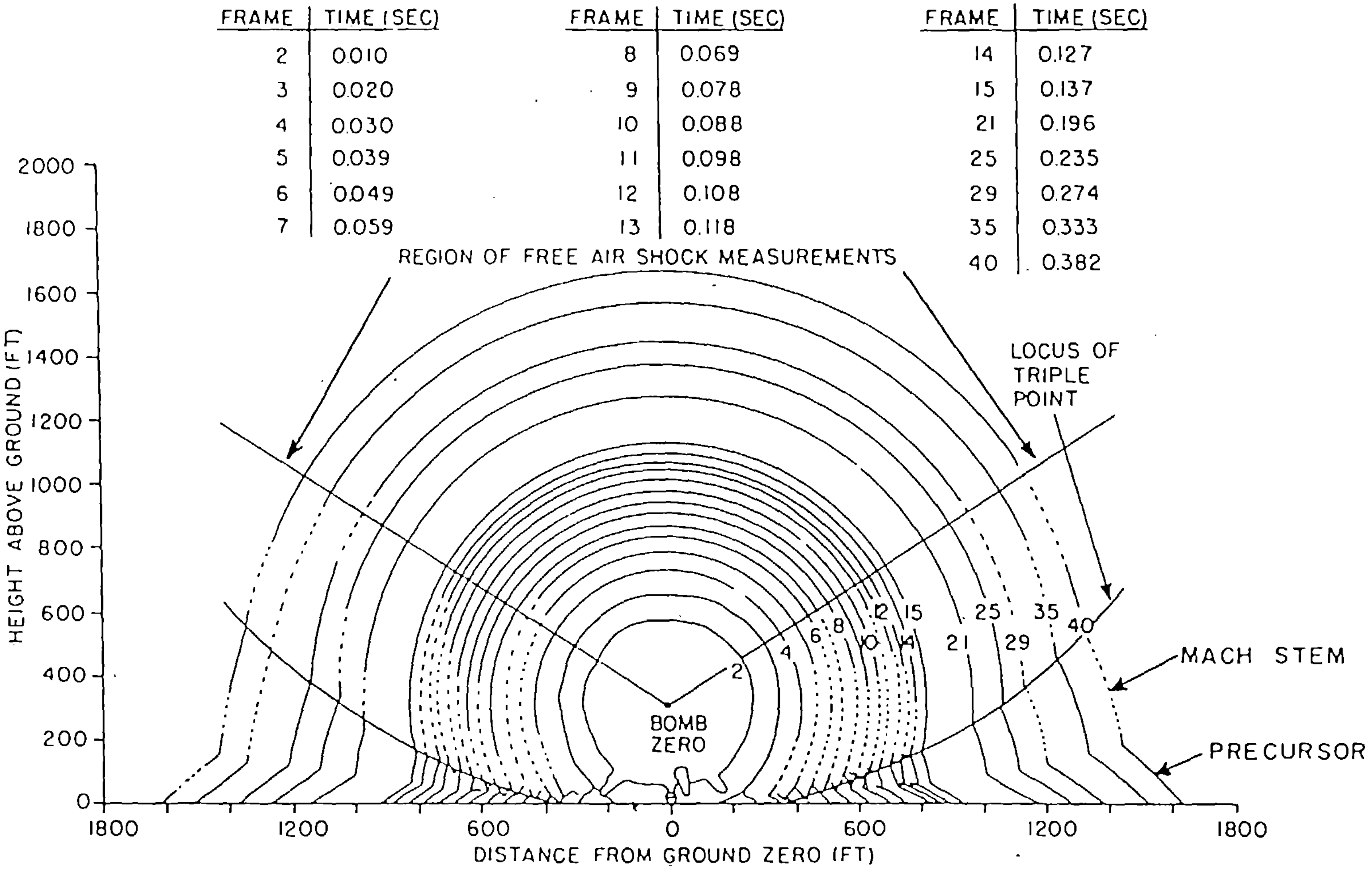


Fig. 2.29—(Continued).

Reproduced from best available copy.

[redacted]



FRAME	TIME (SEC)	FRAME	TIME (SEC)	FRAME	TIME (SEC)
2	0.010	8	0.069	14	0.127
3	0.020	9	0.078	15	0.137
4	0.030	10	0.088	21	0.196
5	0.039	11	0.098	25	0.235
6	0.049	12	0.108	29	0.274
7	0.059	13	0.118	35	0.333
				40	0.382

Fig. 2.30—Precursor Shock Contours, Shot 1.

[redacted]

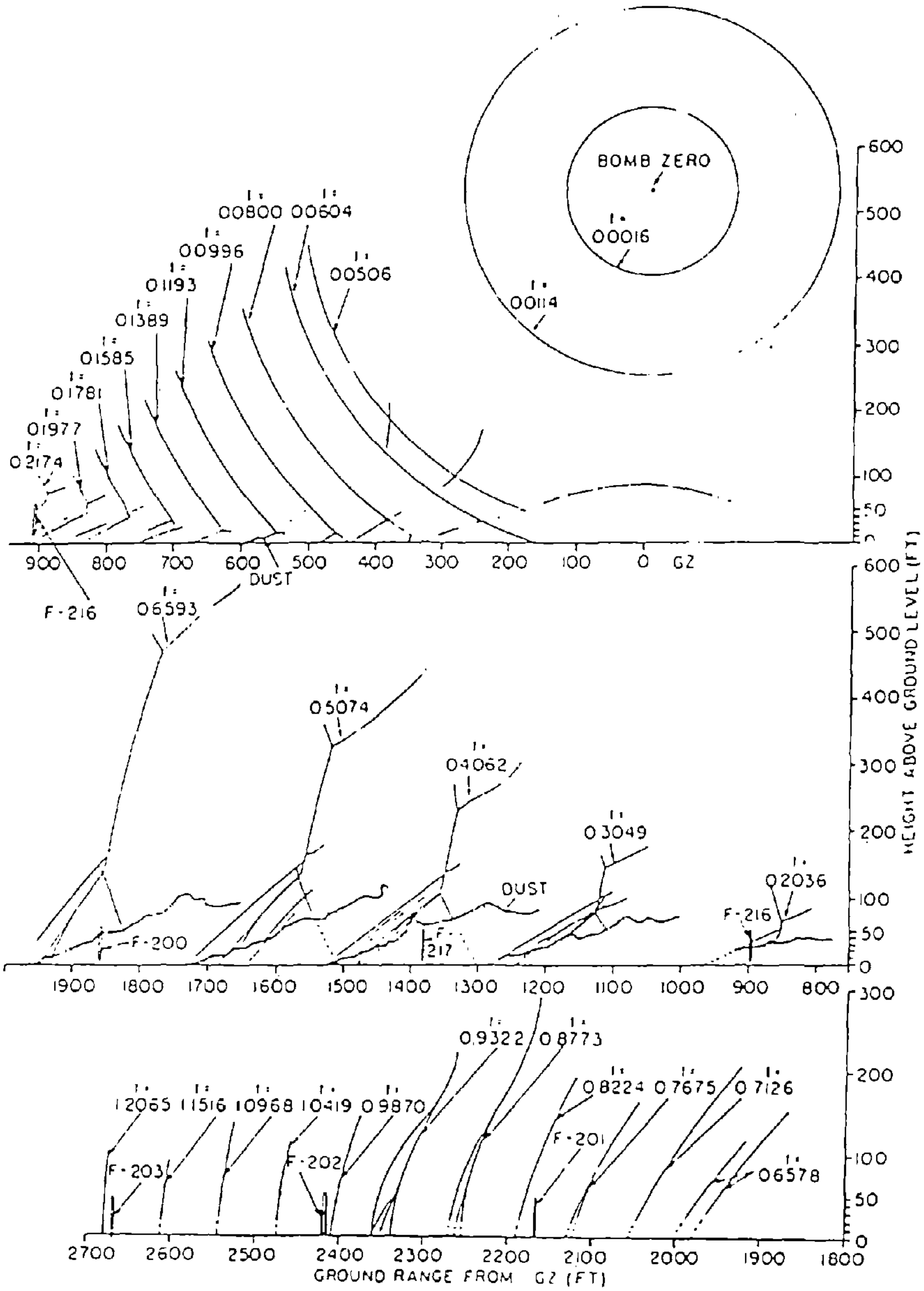


Fig. 2.31 — Precursor Shock Contours, Shot 10.

[redacted]

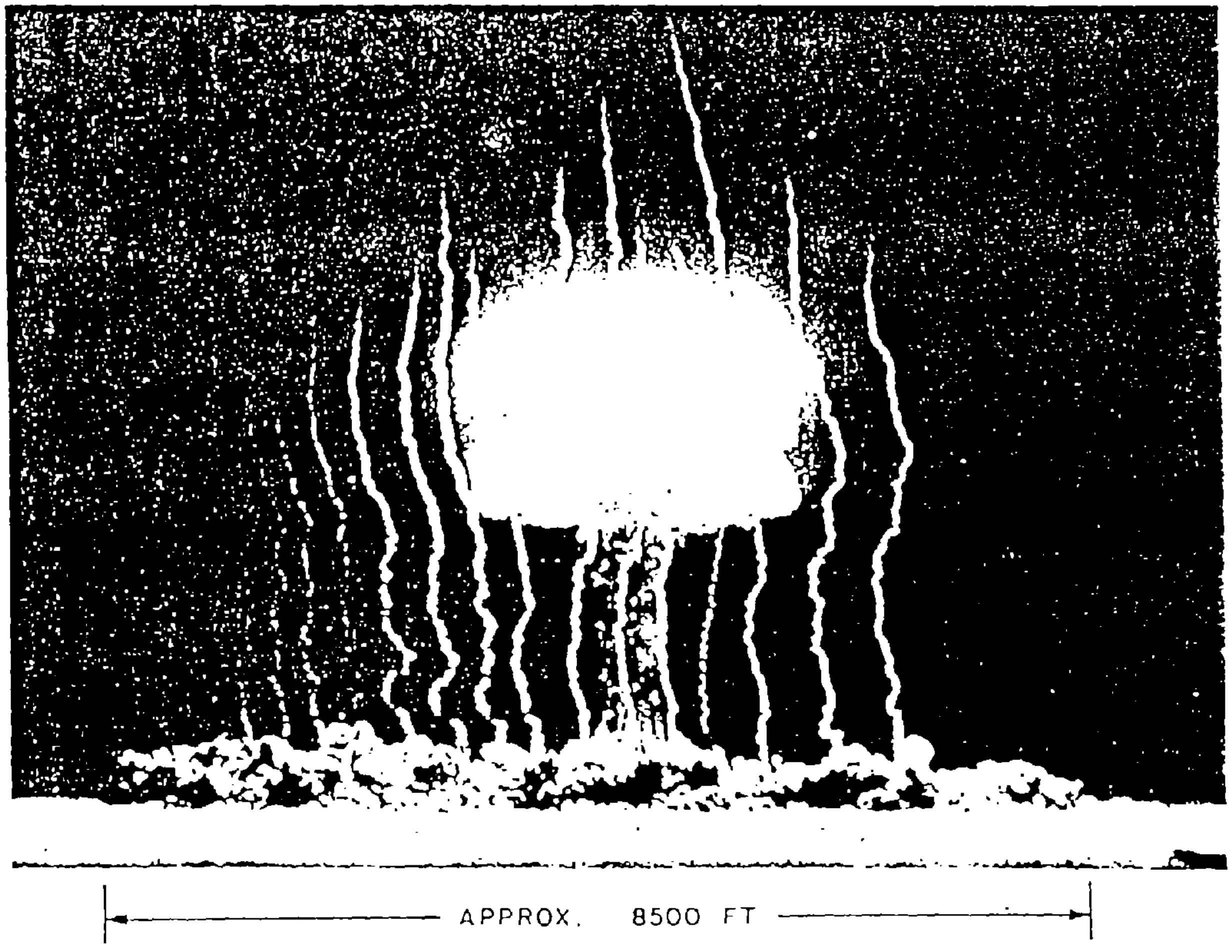


Fig. 2.32—Photograph of Dust Pedestal, Shot 11.

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[redacted]

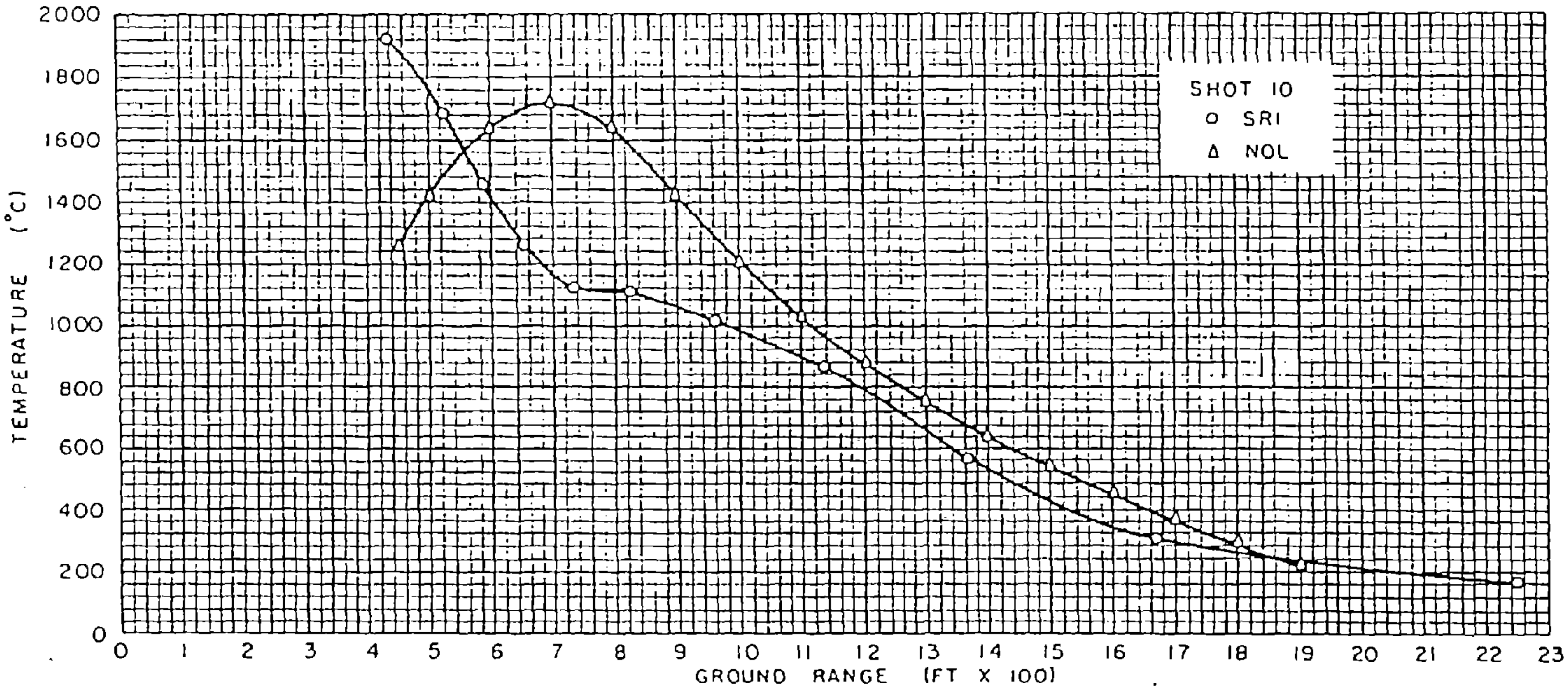


Fig. 2.33—Preshock Air Temperature, Shot 10.

[redacted]

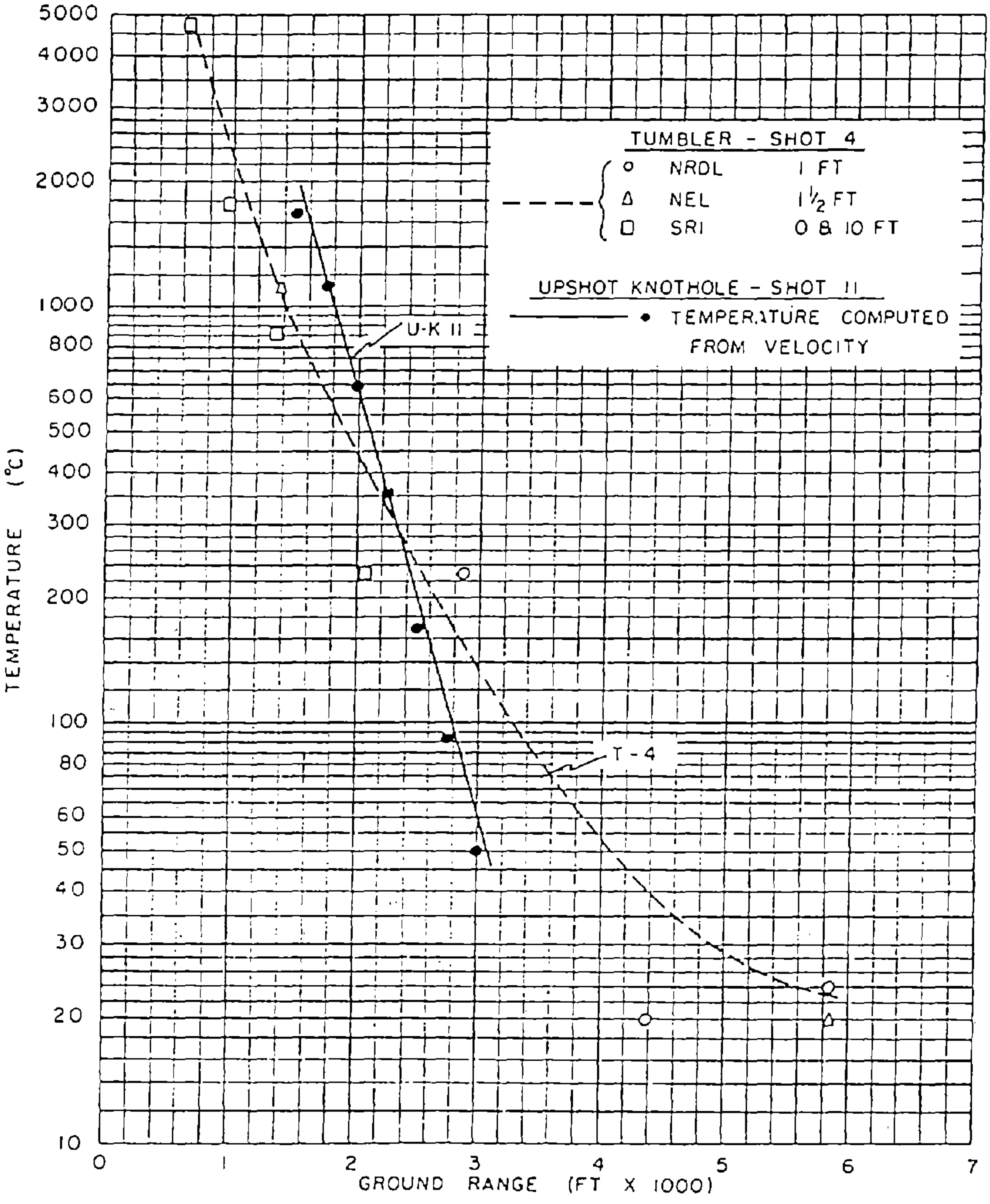


Fig. 2.34 — Preshock Air Temperature, Shot 11 and TUMBLER 4.

[redacted]

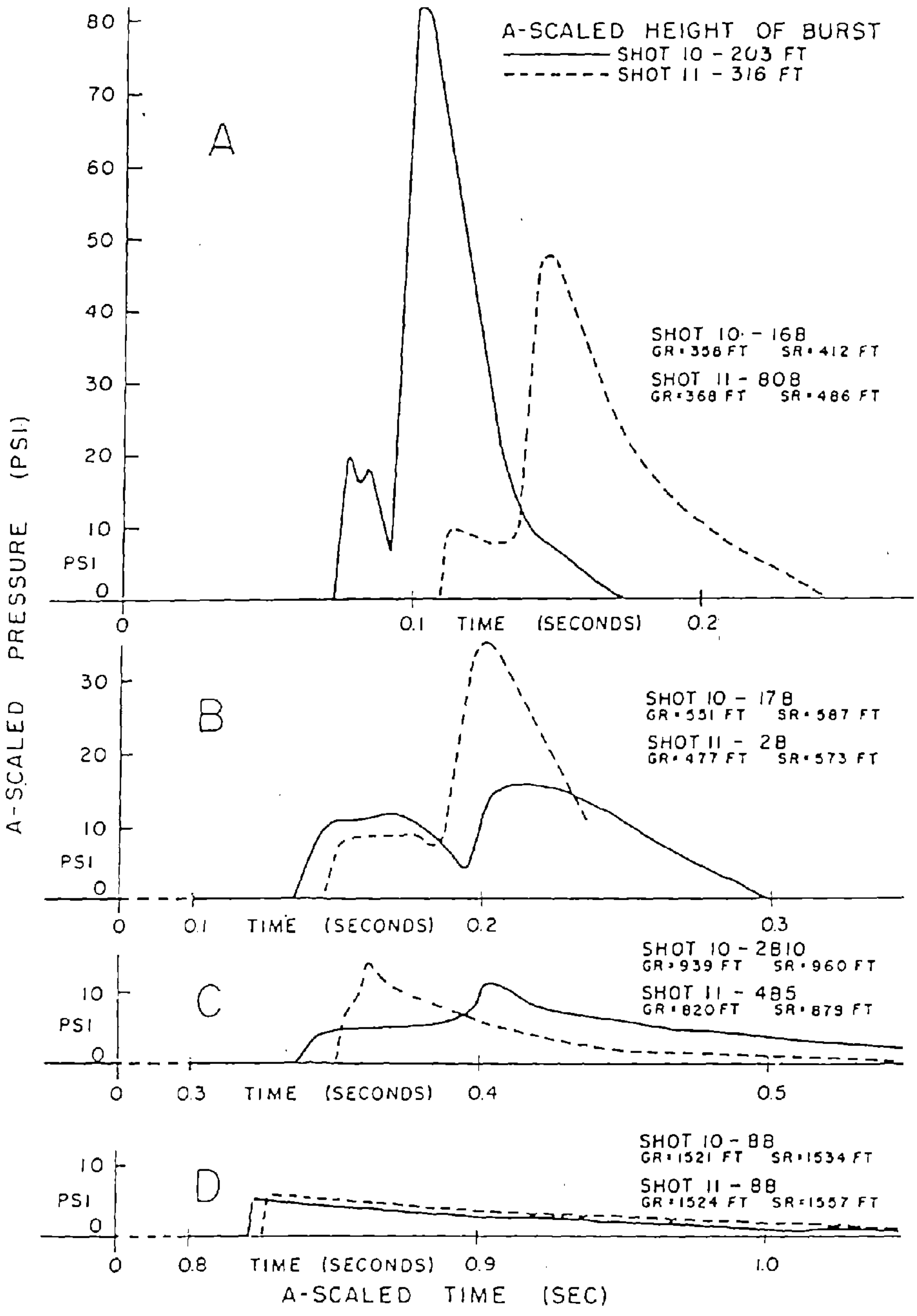


Fig. 2.35—A-Scaled Overpressure Vs Time Records, Shots 10 and 11.

[redacted]

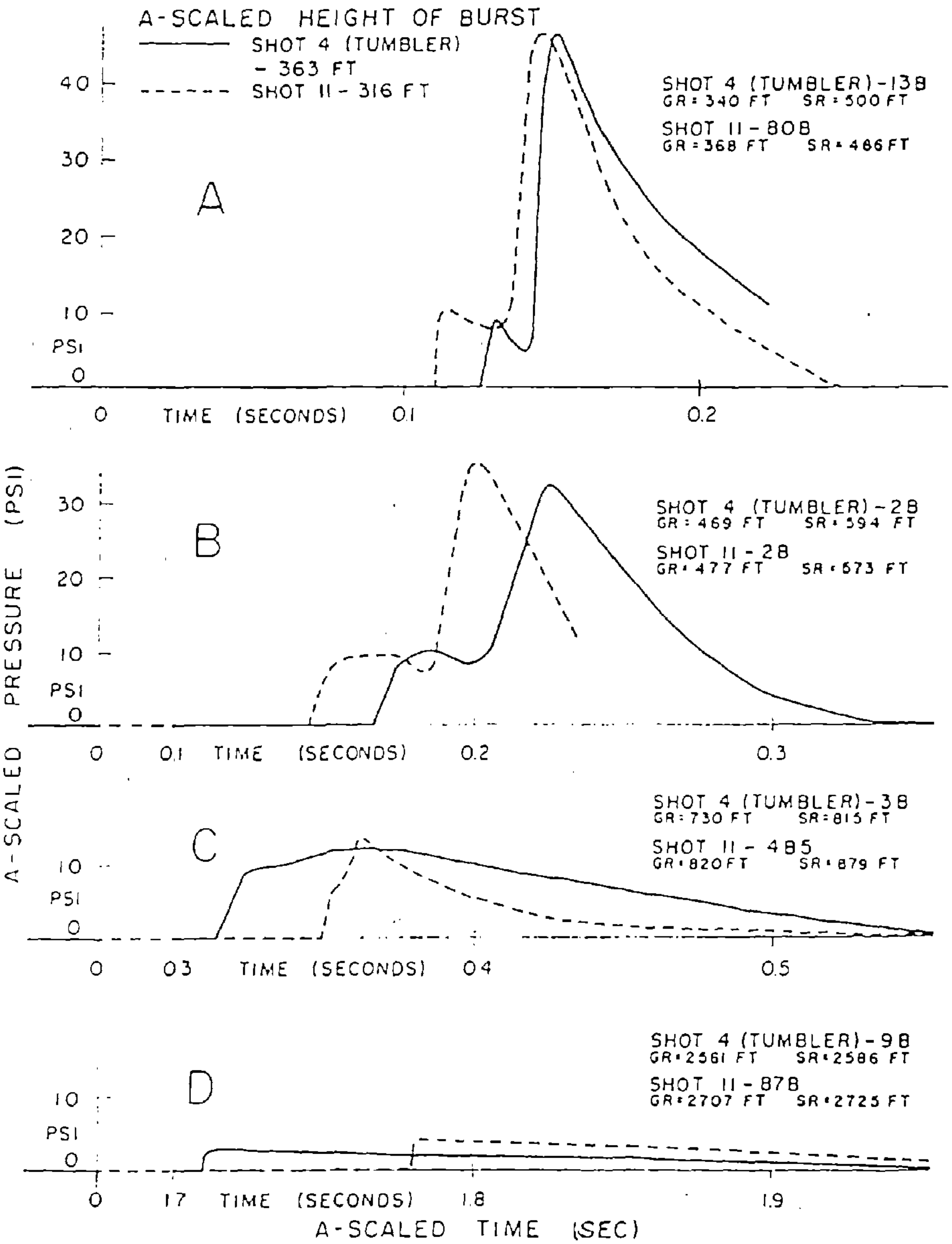


Fig. 2.36 — A-Scaled Overpressure Vs Time Records, Shots 11 and TUMBLER 4.

[redacted]

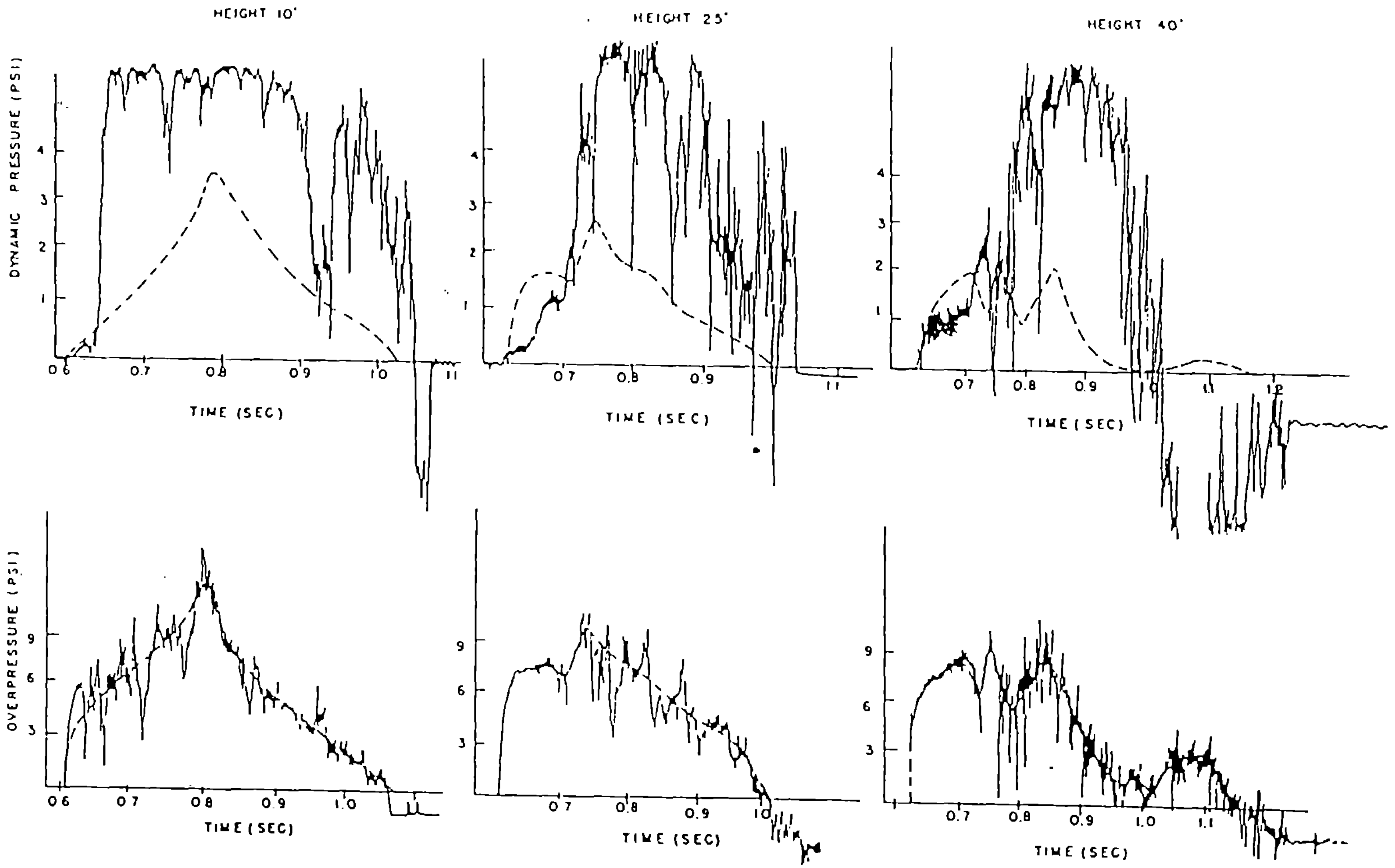


Fig. 2.37—Dynamic Pressure and Static Overpressure Vs Time, 2000 Ft, Shot 10.

[redacted]

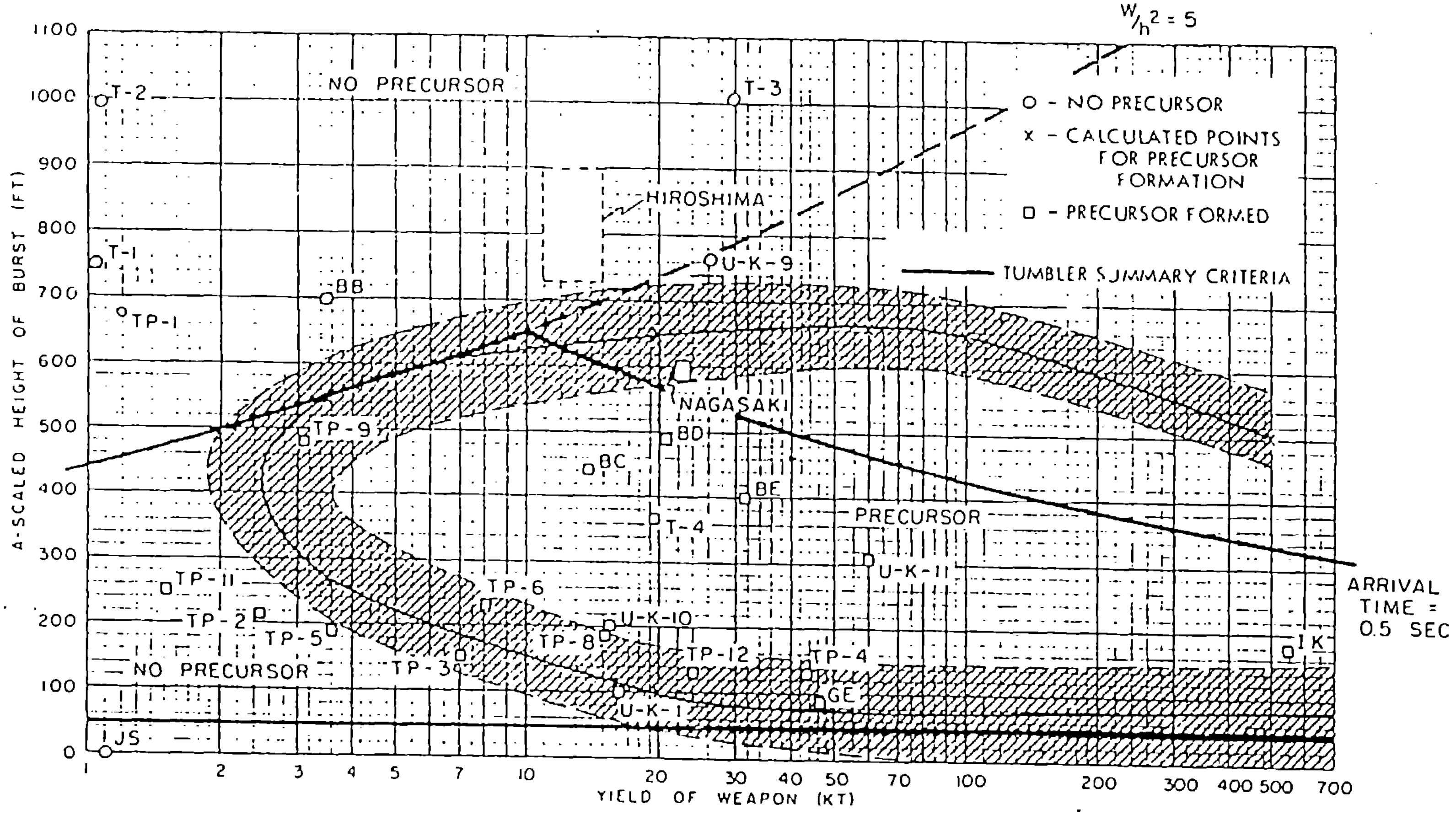


Fig. 2.38—Comparison of Precursor Criteria.

[redacted]

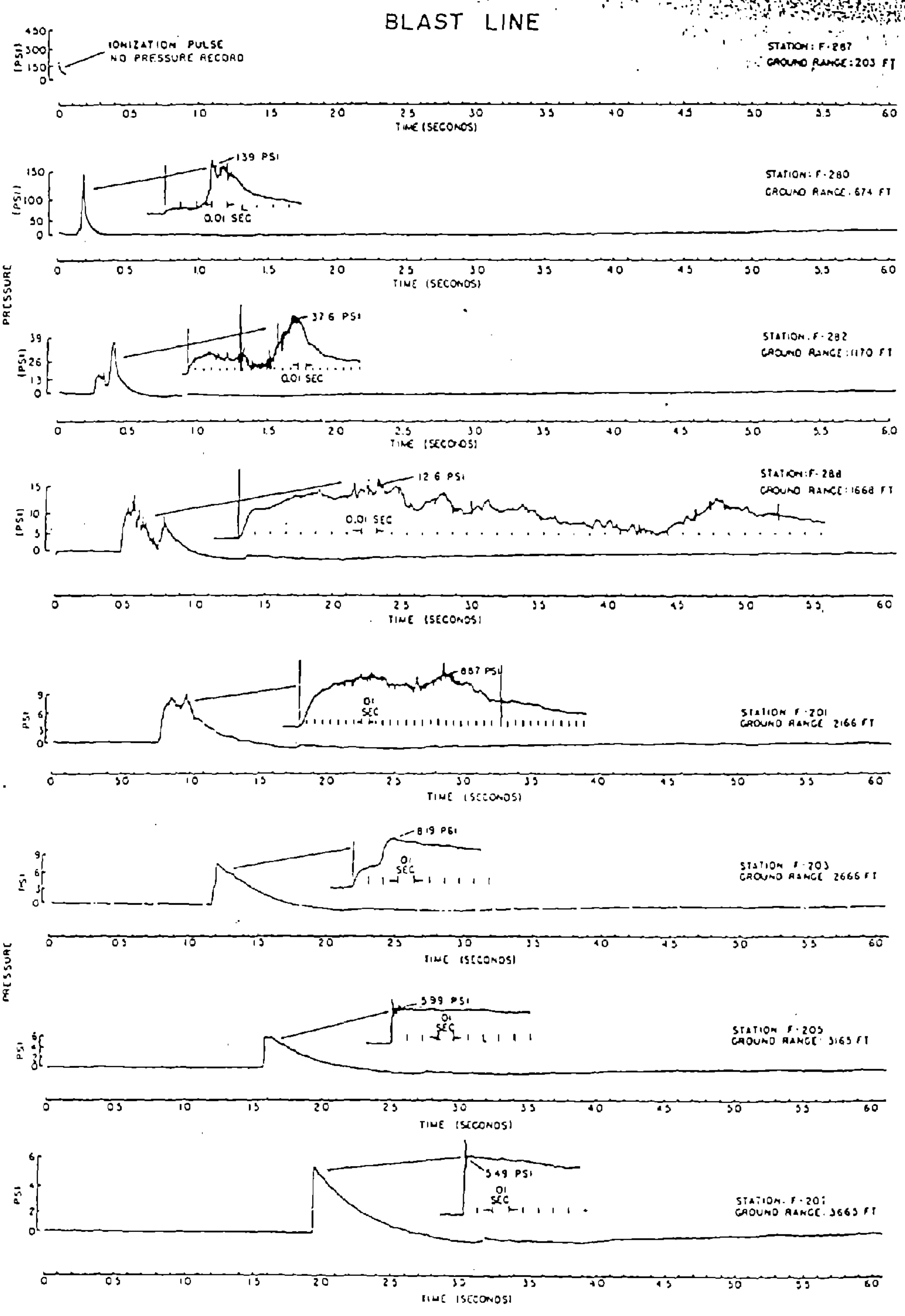
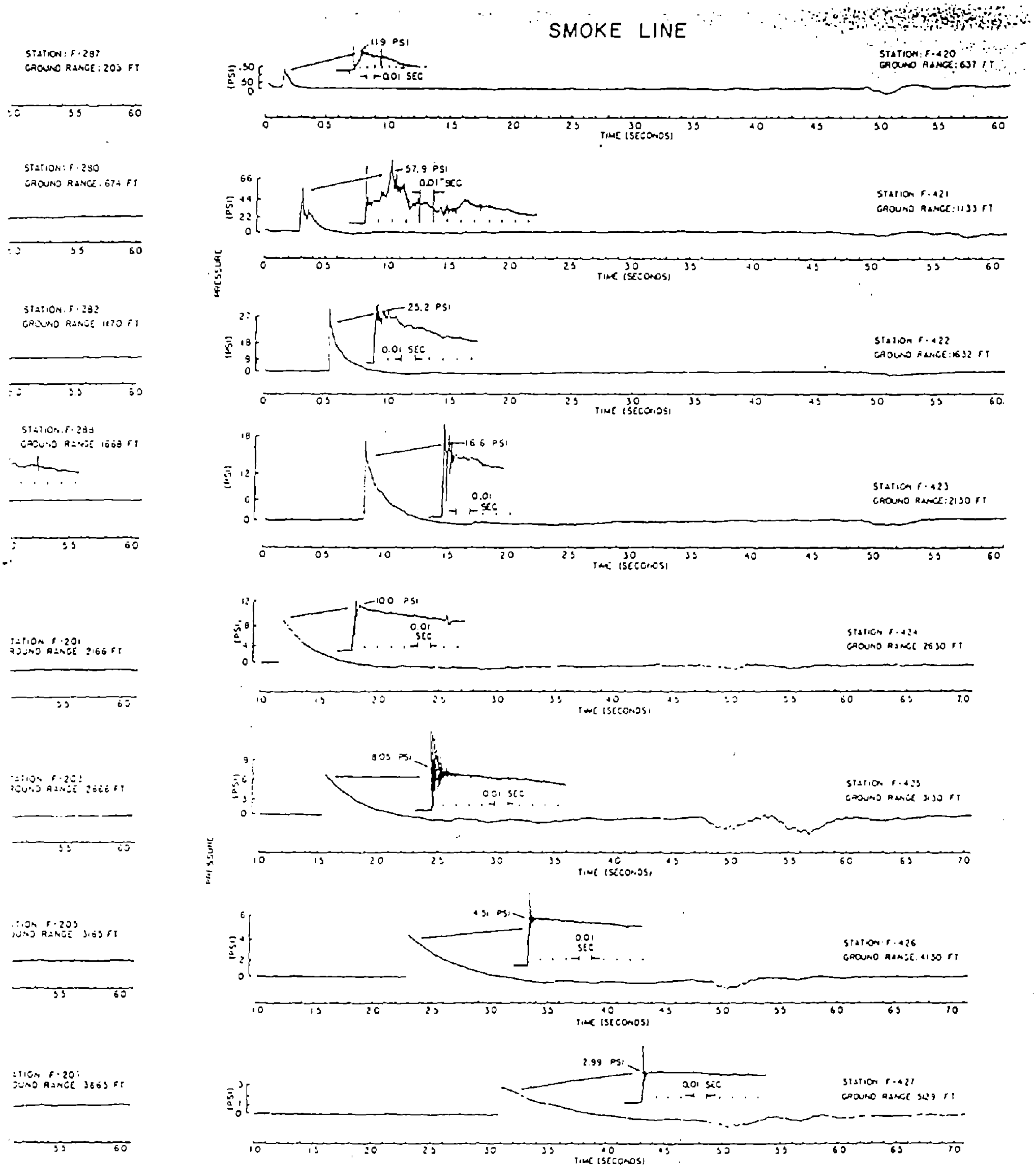


Fig. 2.39—Overpressure Vs Time Records

[redacted]



Vs Time Records Along Main Blast Line and Smoke Line, Shot 10.

85–86

[redacted]

84

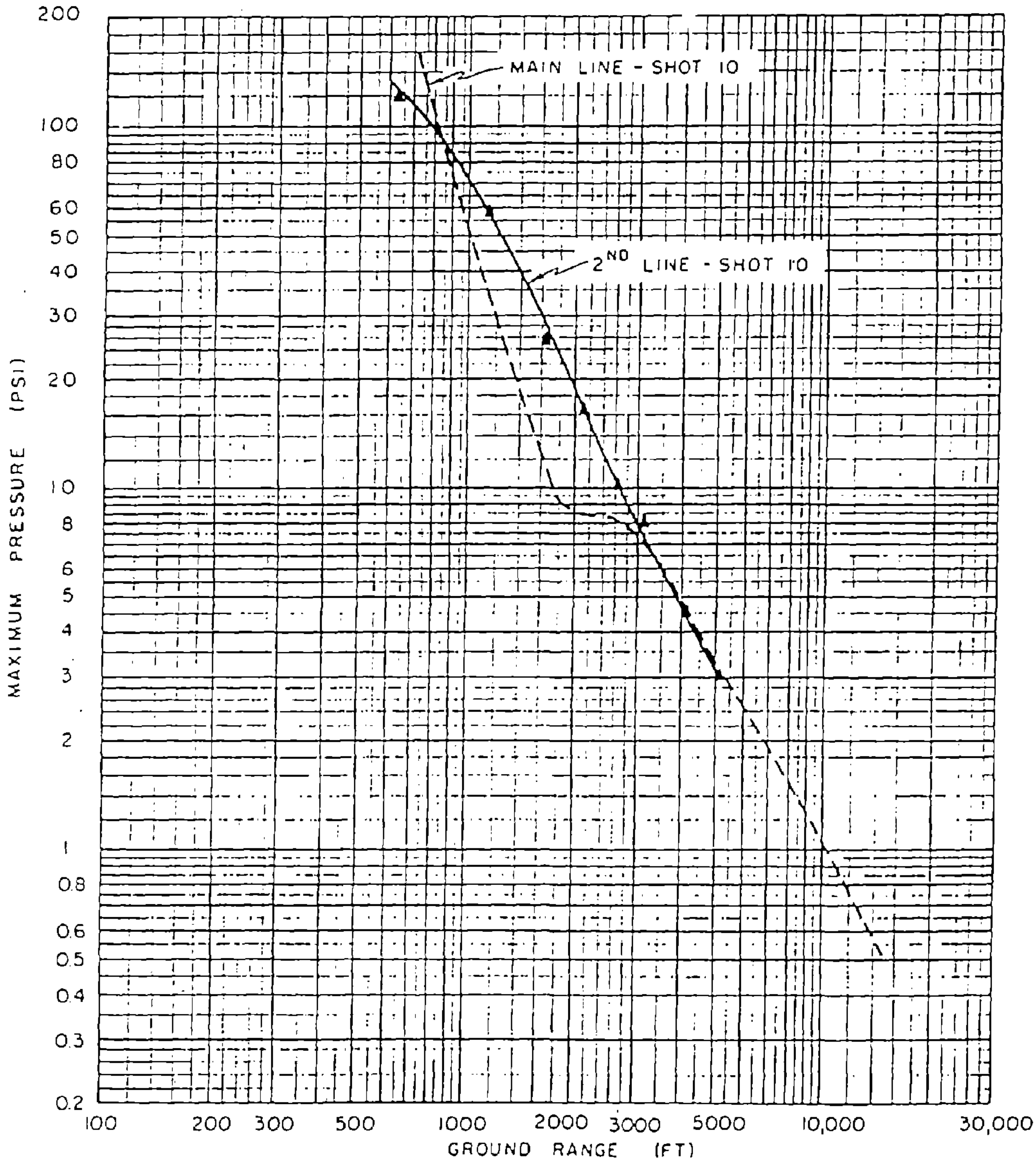


Fig. 2.40—Surface-level Peak Overpressure Vs Ground Range, Main Blast Line and Smoke Line, Shot 10.

[redacted]

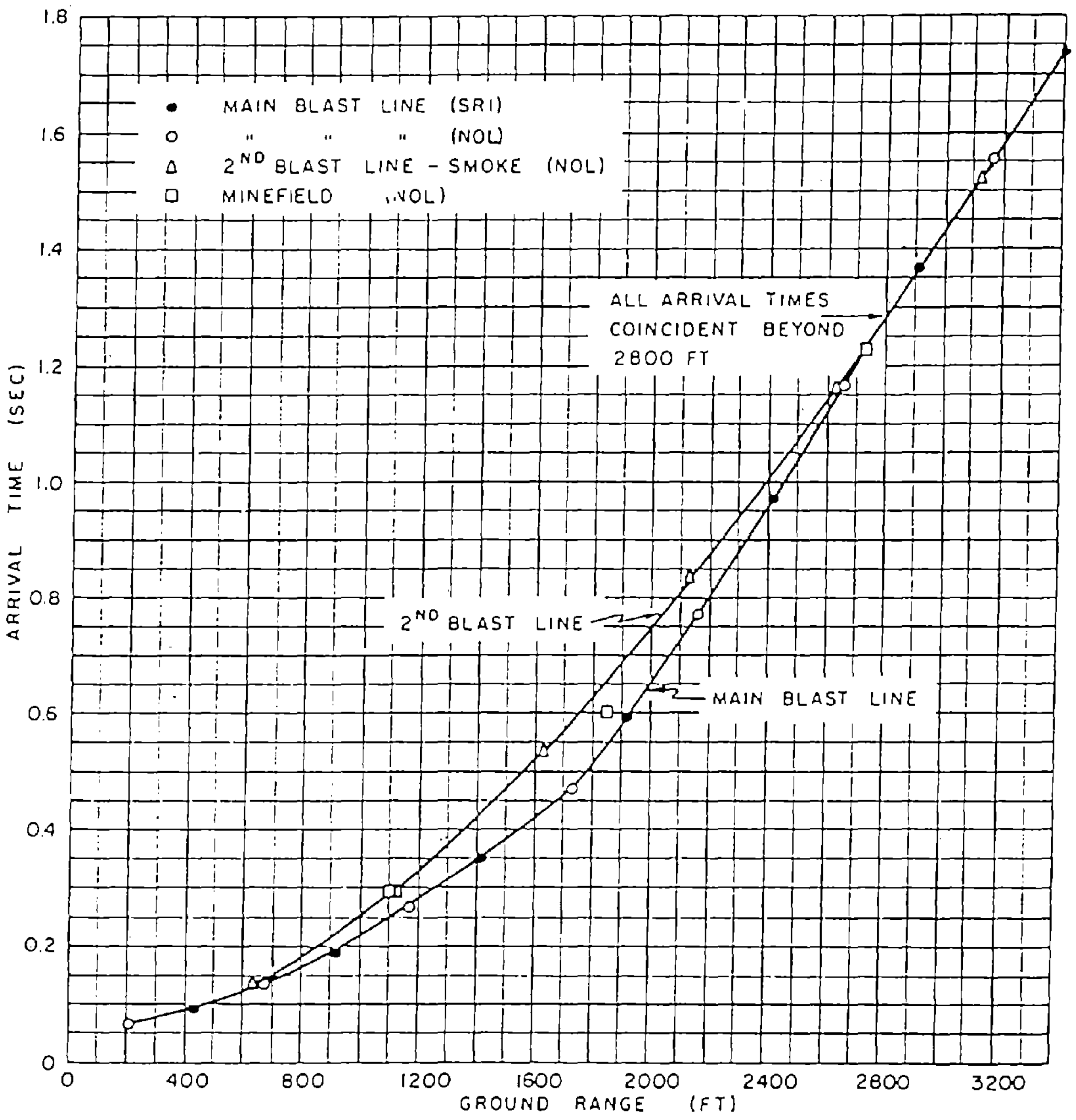
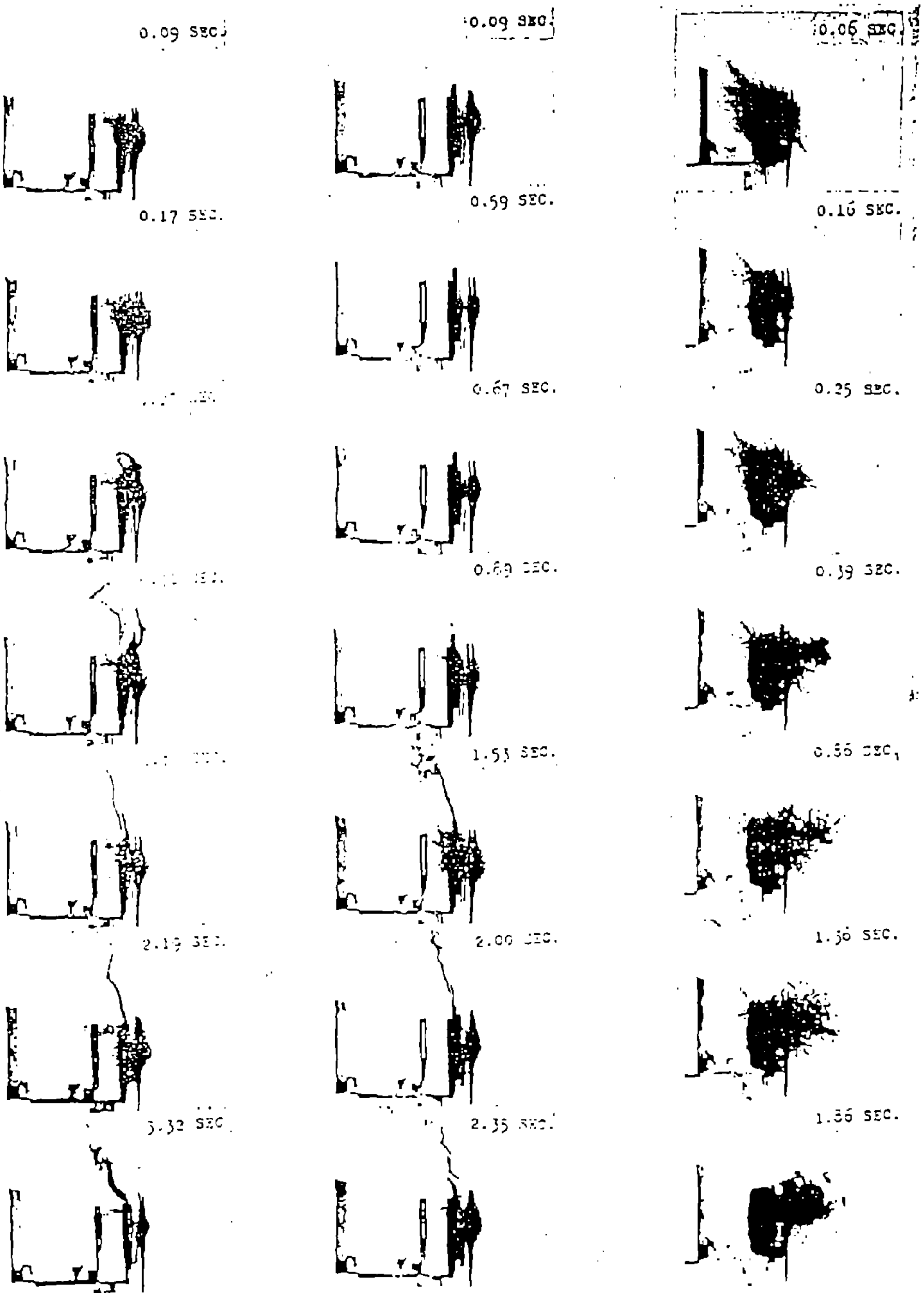


Fig. 2.41 — Arrival Time of Initial Disturbance Along Main Blast Line and Smoke Line, Shot 10.

[redacted]



(a) (b) (c)

Fig. 2.42—Photographs of Popcorning Phenomenon in the Laboratory. (a) Black Asphalt Roofing Paper. (b) Black Ceramic Tile. (c) Frenchman Flat Adobe.

[redacted]

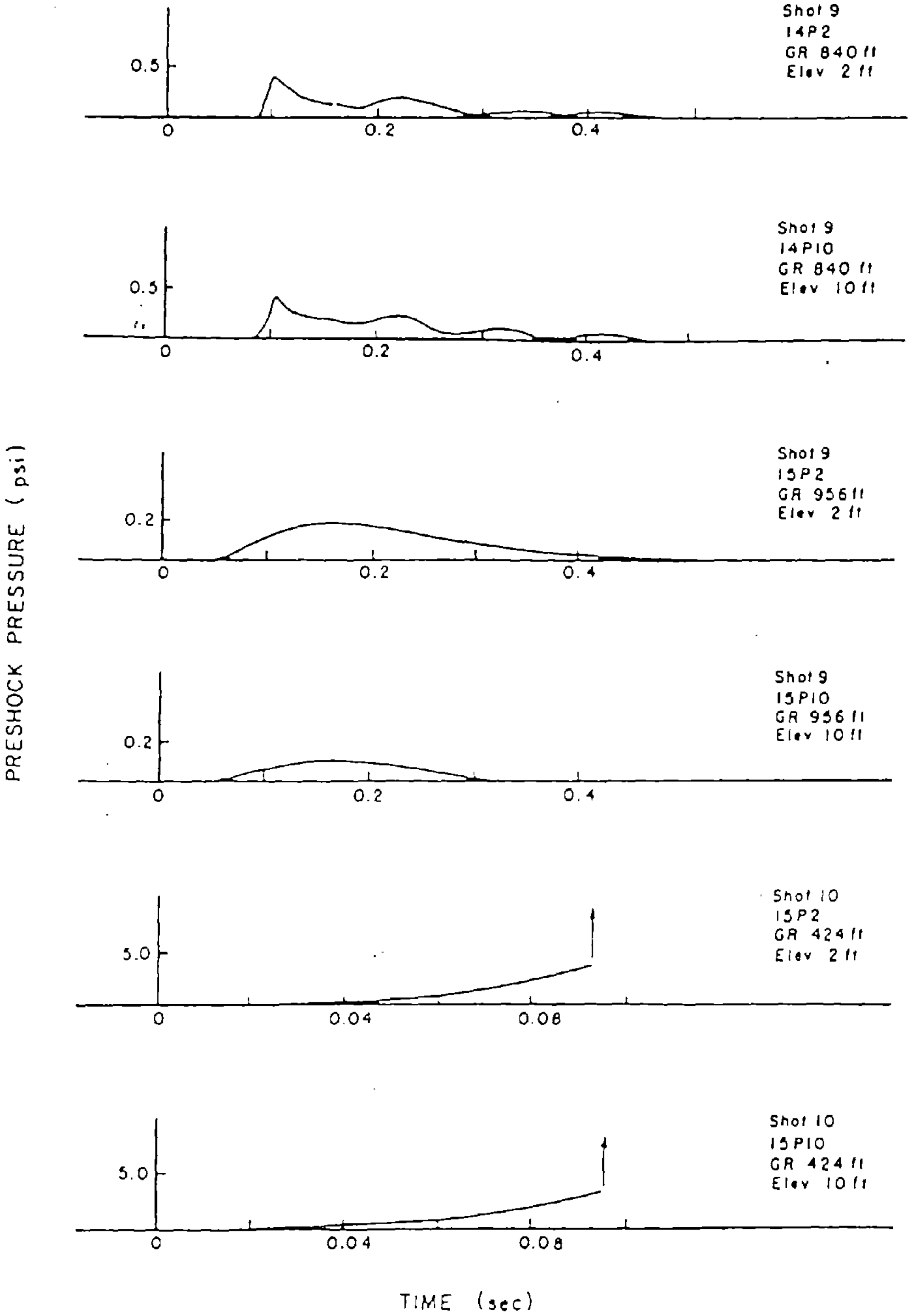


Fig. 2.43 — Preshock Pressure Vs Time Records, Shots 9 and 10.

[redacted]

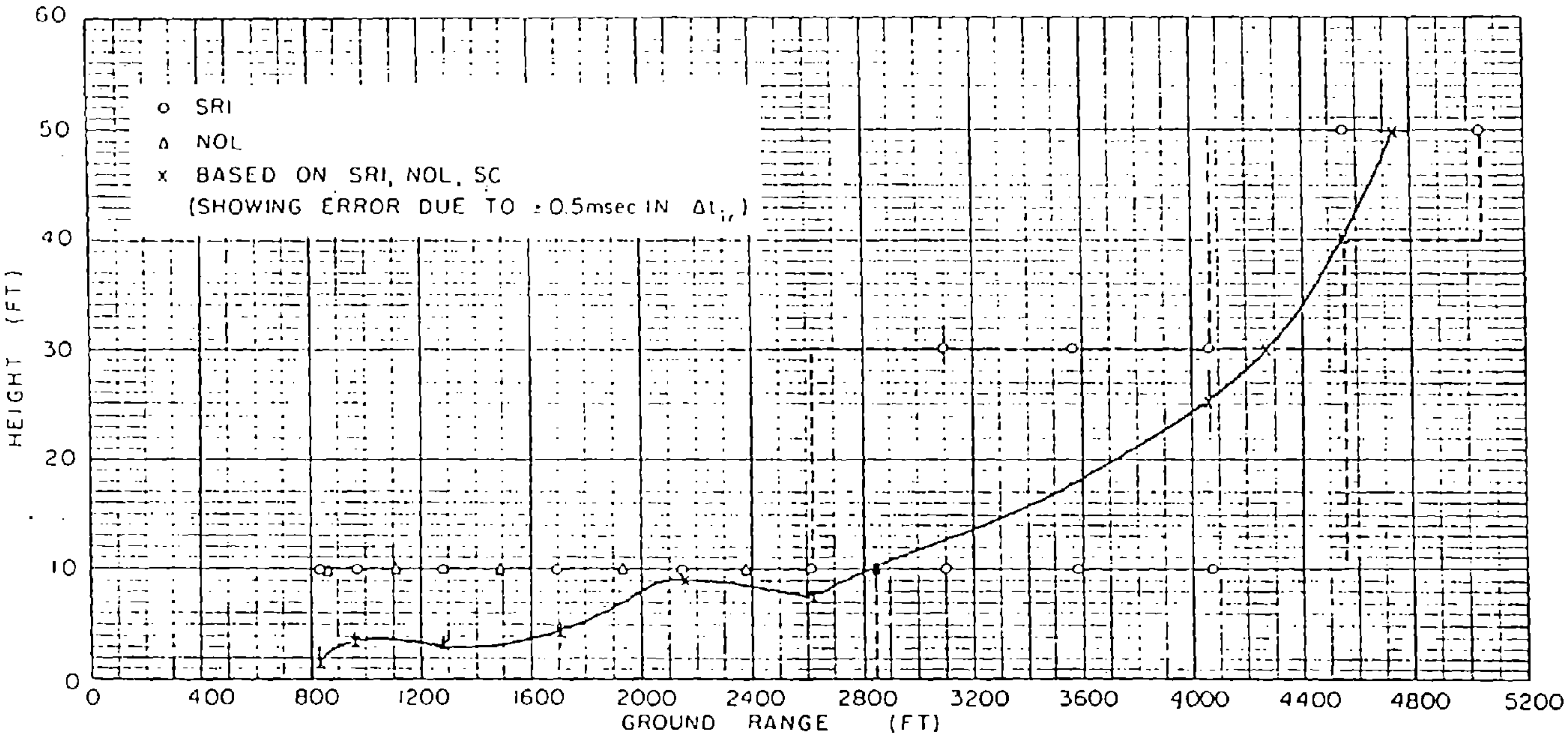


Fig. 2.44 — Mach Stem Height Vs Ground Range, Shot 9.

[redacted]

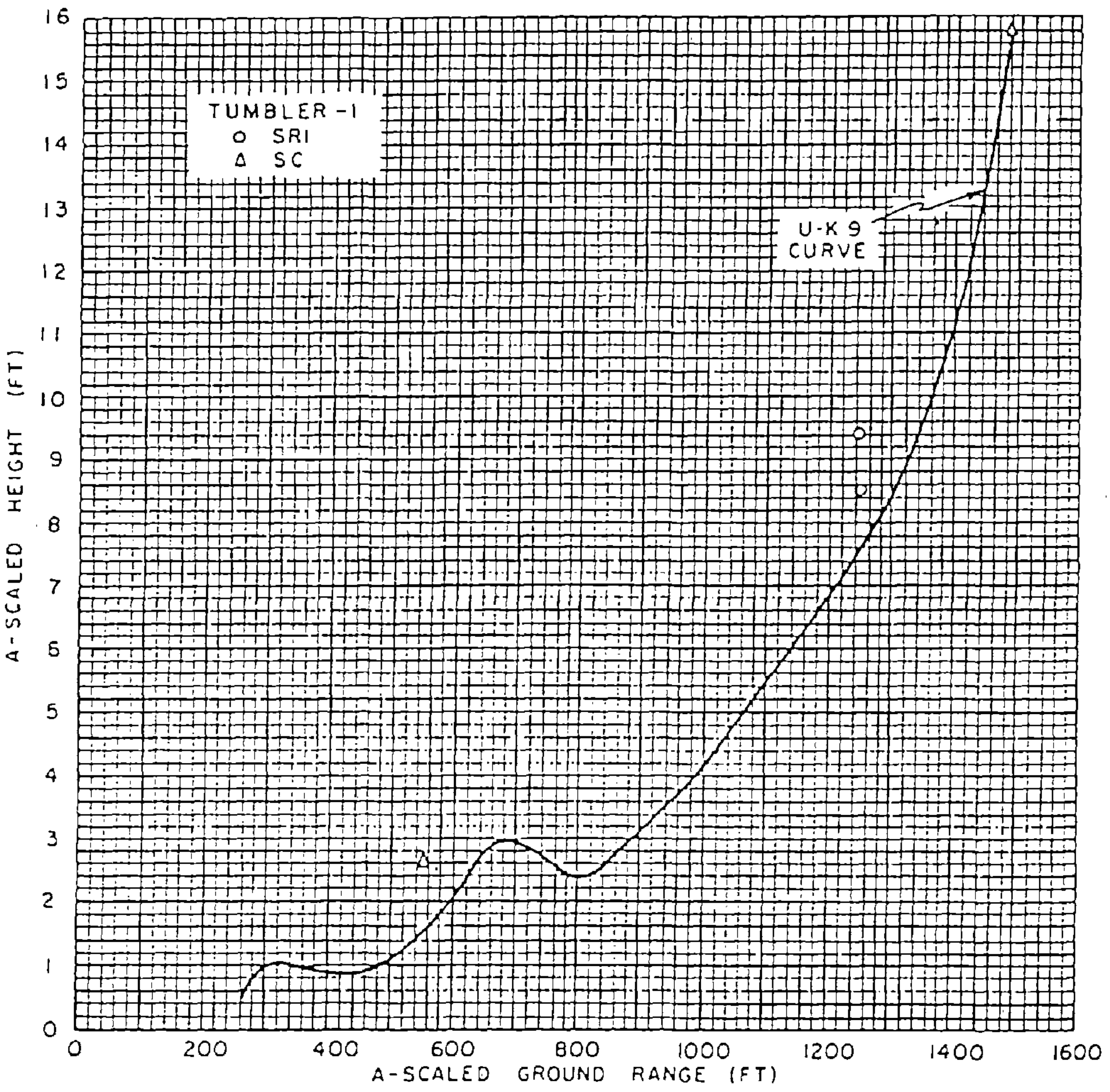


Fig. 2.45 — A-Scaled Mach Stem Height, Comparison of Shot 9 and TUMBLER 1.

[redacted]

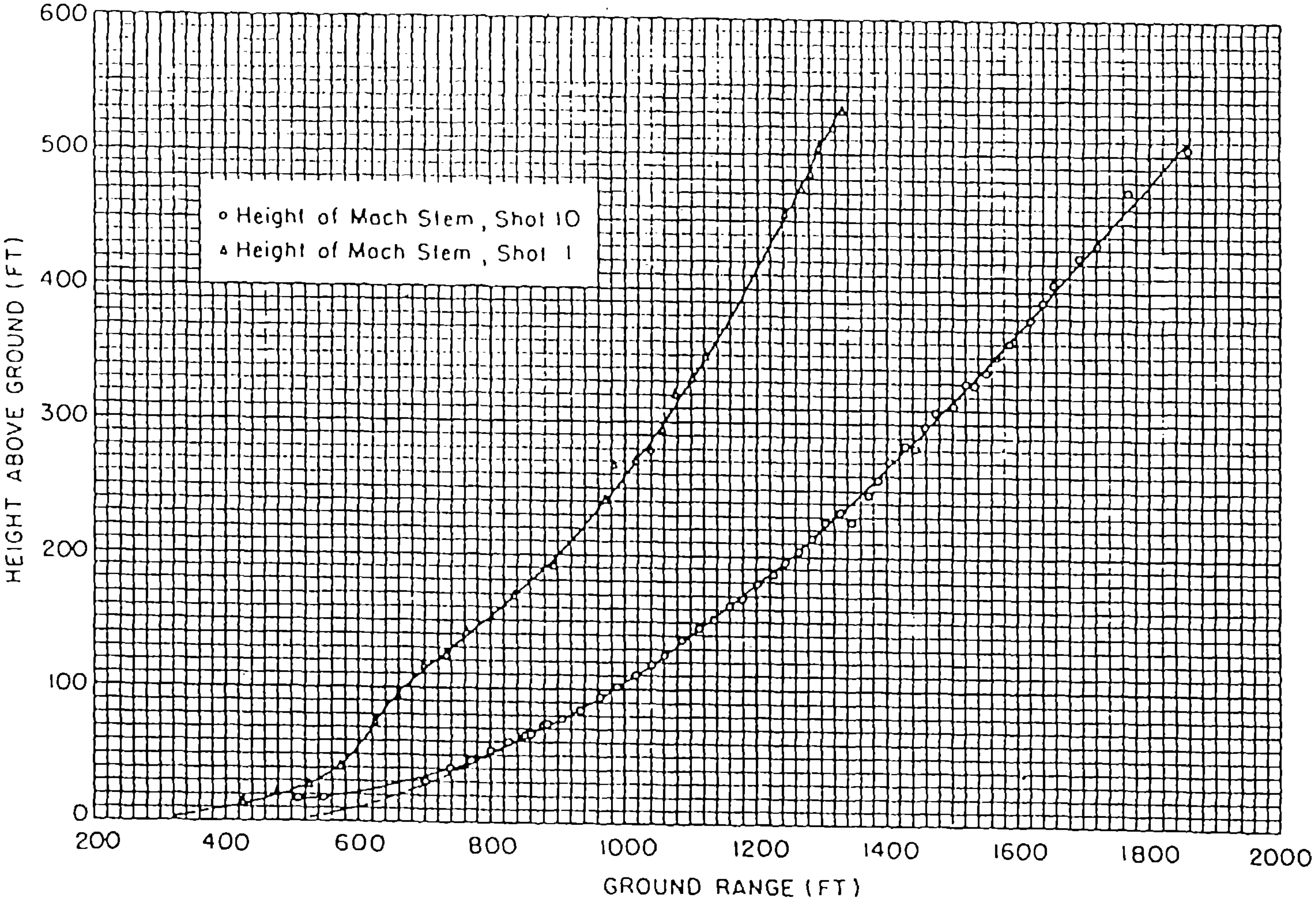
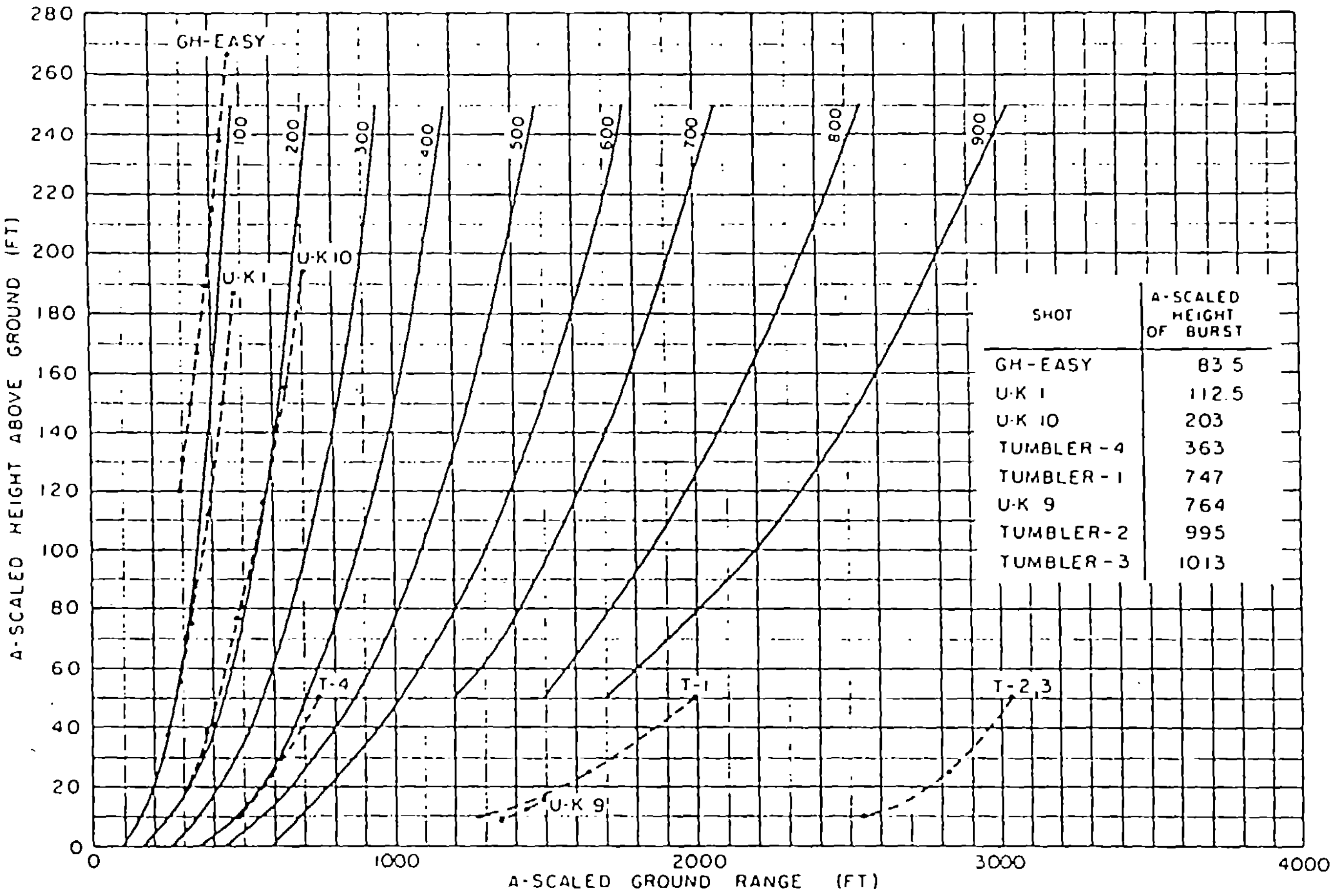


Fig. 2.46—Mach Stem Height Vs Ground Range, Shots 1 and 10.

[redacted]



SHOT	A-SCALED HEIGHT OF BURST
GH-EASY	83.5
U-K 1	112.5
U-K 10	203
TUMBLER-4	363
TUMBLER-1	747
U-K 9	764
TUMBLER-2	995
TUMBLER-3	1013

Fig. 2.47—Comparison of Scaled Nuclear and HE Data for Mach Stem Height.

[redacted]

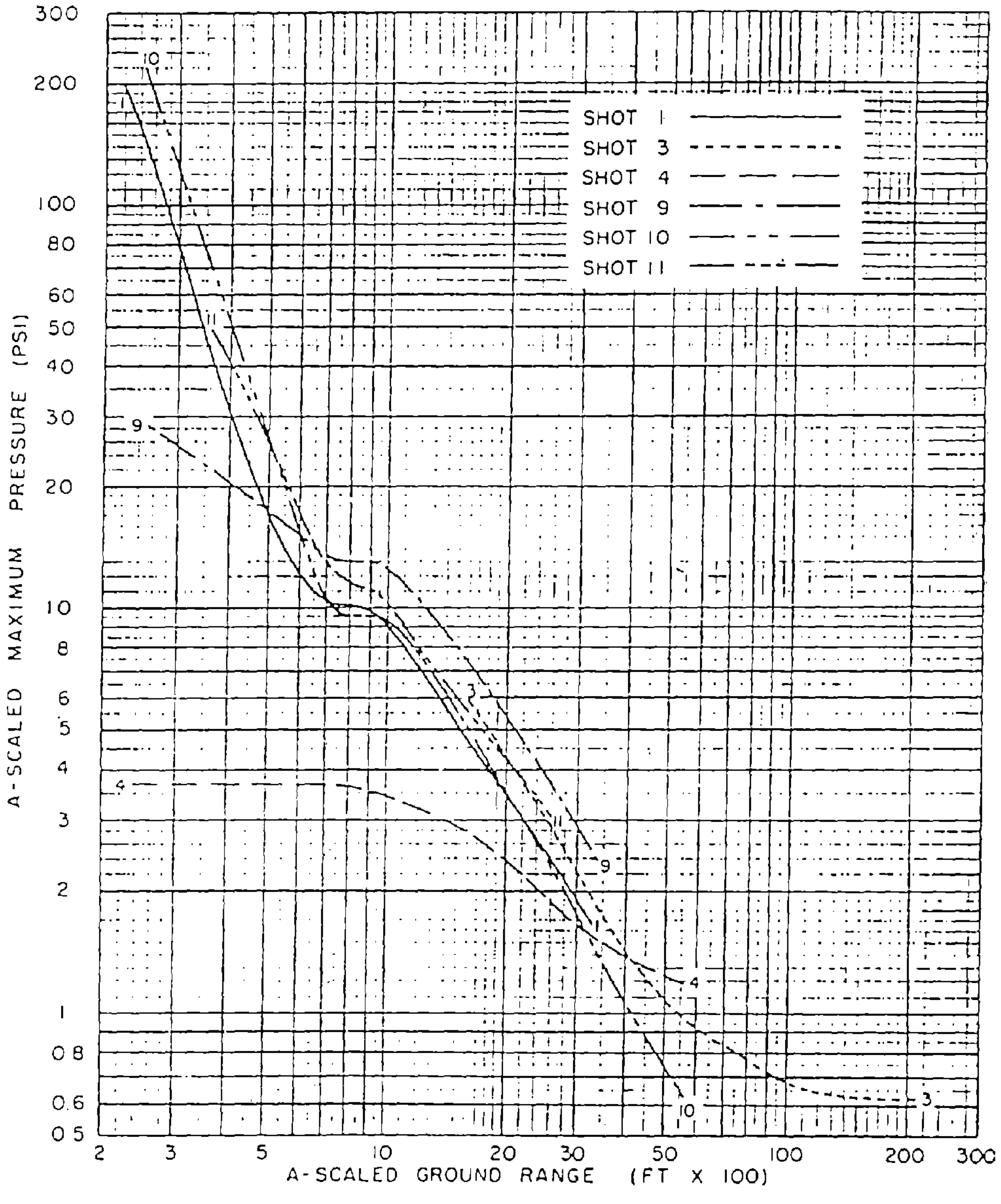


Fig. 2.48—Ground-level Peak Overpressures Vs Ground Range, Shots 1, 3, 4, 9, 10, and 11 (A-Scaled).

[redacted]

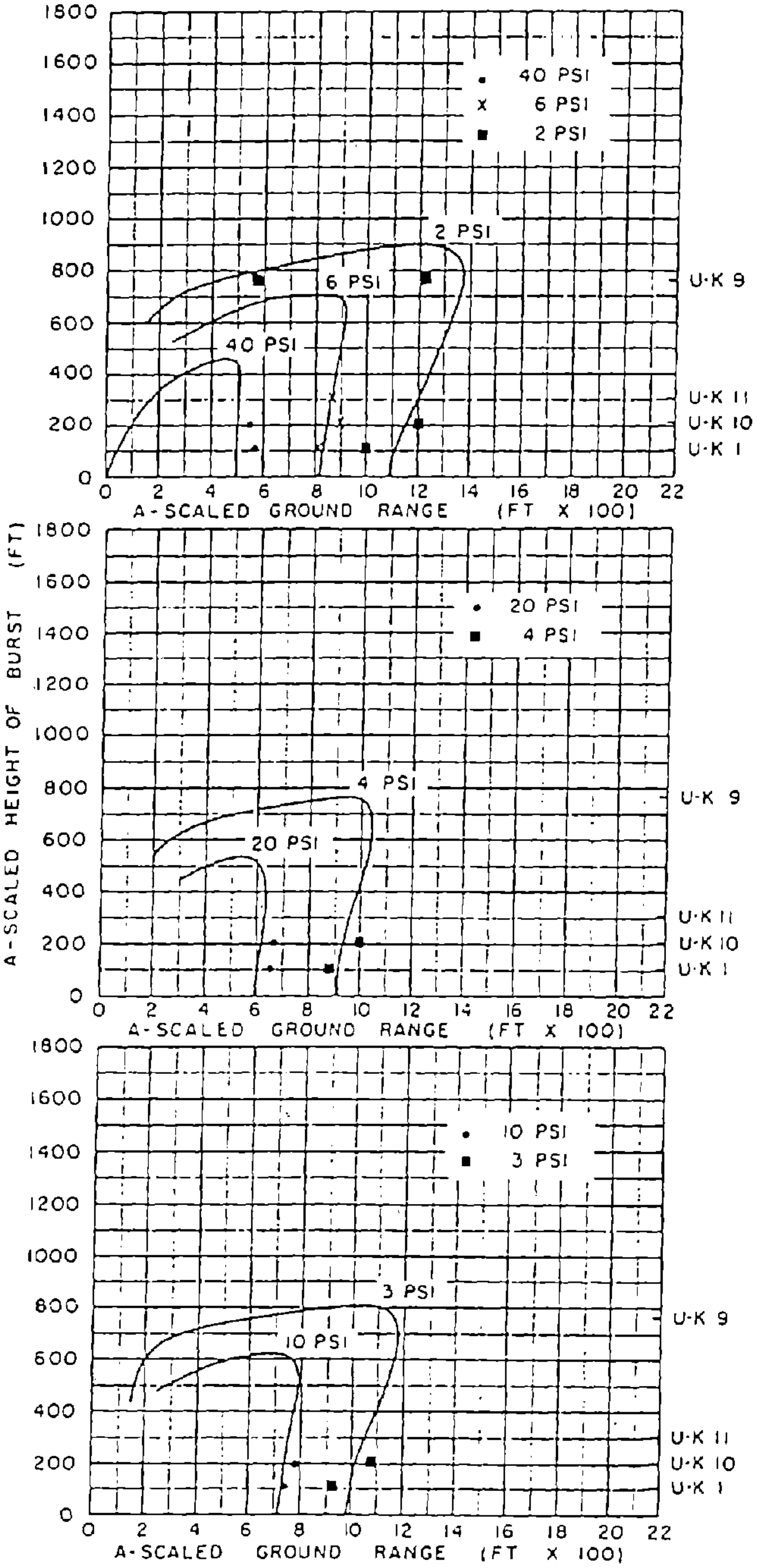


Fig. 2.49—Comparison of Ideal Peak Overpressure Height-of-burst Curves with U-K Data.

[redacted]

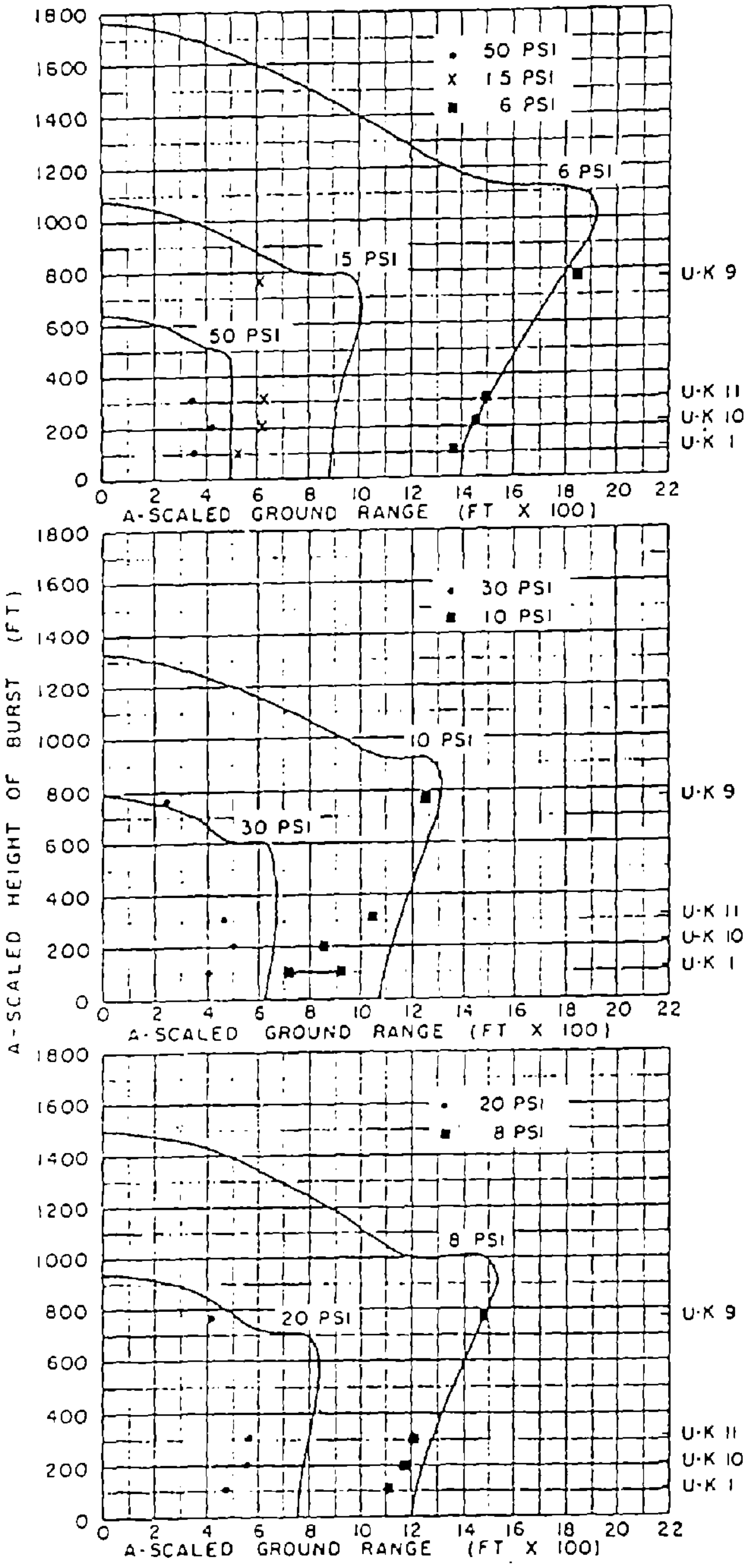


Fig. 2.50 — Comparison of Ideal Peak Dynamic Pressure Height-of-burst Curves with U-K Data.

[redacted]

TABLE 3.1 — Total Thermal Energy and Air Transmissivity, All Shots

Shot	Total weapon yield (KT)	Total thermal energy (KT) NRL*†	USNRDL†	AFCRC†	AFSWP-503 (Calculated)	Air transmissivity‡
1	16.2	6.0		7.9§	6.0	94
2	24.5	11		8.7§	8.9	94
3	0.20	0.028	0.020	0.0016¶		95
4	11.0	3.8	4.0	3.3§ 5.0¶	4.2	95
5	23	9.3		8.9§	8.3	95
6	0.22			0.015¶		96
7	43.4	15		17.6§ 16.7¶	15.2	95
8	27	11		10.3§	9.7	93
9	26	10	10.1	10.4¶	9.4	92
10	14.9	5.2	5.2	6.5§ 4.7¶	5.5	91
11	60.8	18.1**	20.3		21	98**

*Data selected from NRL Report No. 4395, RD No. 420, based upon conversation with Dr. L. F. Drummeter, Jr., 7 December 1954.

†See text for explanation of scatter and absorption corrections.

‡NRL results on specular transmissivity in per cent per statute mile for light of 5500A° wave length. See NRL Report 4395, RD No. 420.

§As measured by AFCRC at local stations, 1 to 2 miles from IGZ.

¶As measured by AFCRC at remote stations, $6\frac{1}{2}$ to 14 miles from IGZ.

**As obtained with NRL equipment operated by Dr. Herman Hoerlin of LASL. The value for air transmissivity is doubtful: Rayleigh scattering alone limits the transmission to about $96\frac{1}{2}$ per cent per mile. It should be noted that the thermal yield, as corrected for scatter and absorption, will be low if too high a value is used for transmission, as was in this case.

have been corrected for air transmissivity and field of view of the receiver. Thus the thermal yields in Table 3.1 for the local AFCRC stations are of the order of 10 per cent lower than would be obtained if further corrected for absorption. Thermal yields calculated from the AFCRC data obtained at the more distant remote stations, if further corrected, would be approximately 10 to 15 per cent greater.

The fact that all the elements entering into the calculation of thermal yields have not been considered by NRDL and AFCRC is explained by a certain amount of confusion regarding the method for making the required corrections and also by the relative importance attached by NRDL and AFCRC to each of the correction factors. It appears that it would be of considerable interest to reanalyze the available data on thermal yields, incorporating into the analysis the considerable quantity of data on scatter and absorption obtained, but not analyzed, by NRDL from this operation and at Operation TUMBLER-SNAPPER. Of the calorimeter readings obtained at the two operations, between one-third and one-half of the readings were obtained with calorimeters viewing the ground, with calorimeters shielded from view of the fireball, or with calorimeters having fields of view other than the standard 90 deg. Furthermore, the sensing instruments used by NRL, NRDL, and AFCRC are substantially different one from the other in spectral sensitivity and field of view to warrant examination and further analysis of the data and performance of the instruments. The suggested analysis, it is believed, would test more rigorously Drummeter's method for correcting thermal measurements in Nevada and also might help to clarify parameters entering into the prediction of radiative transfer through real atmospheres. The effort for such an analysis, however, is beyond the scope of this report.

The data on thermal yields are plotted in Fig. 3.2. The straight line log-log relation between thermal yield and radiochemical yield is that published in AFSWP-503, i.e., $E = 0.44W^{0.94}$.

[redacted]

It is seen that the scatter of the NRDL data is least, whereas that of the AFCRC data is greatest. In most cases, however, the agreement between thermal yields as calculated from $E = 0.44W^{0.94}$ is well within ±15 per cent.

3.3.4 Time Vs Intensity

The characteristic variation of radiant intensity with time from the fireball provides two datum points of interest to effects studies, i.e., time of the minimum and time of the second maximum, the data for which are given in Table 3.2 and plotted in Figs. 3.3 and 3.4.

TABLE 3.2 — Times to First Minimum and Second Maximum, All Shots

Shot	Weapon yield (KT)	Time to minimum (msec)					Time to second maximum (msec)			
		NRL*	AFCRC	USNRDL	EG&G†	AFSWP-503‡	NRL*	AFCRC	USNRDL	AFSWP-503‡
1	16.2	19	14.3		14.5	10.9	180	122		129
2	24.5	15	17.5		18.5	13.4	250	166		159
3	0.20	3.8				1.2	8.5			14
4	11.0		11.2	17	10.5	9.0		117	118	106
5	23	15.5	18.2		17.75	13.0	175	162		154
6	0.22	4.4	5.6			1.3	7.5			15
7	43.4	25.5	19.6		23.25	17.8	225	196		211
8	27	19	16.8		19.2	14.1	125	155		166
9	26		16.8	23	17.8	13.8	265	151	179	163
10	14.9		14.0	17	14.9	10.5		124	138	123
11	60.8			27	27.2	21.2			257	250

*Data extracted from NRL Report 4356, RD No. 393. Times to minimum are indeterminate to 2 or 3 msec; times to maximum to about 25 msec. The times correspond to minima and maxima in black body temperatures of the fireball.

†EG&G bhangmeter results. (See Sec. 3.3.).

‡Calculated from the scaling relations given in AFSWP-503.

According to AFSWP-503, the time to the minimum in radiant emission is related to the yield by the expression $t_{min} = 2.7W^{1/2}$, where t_{min} is in milliseconds and W is in kilotons. EG&G bhangmeter times are related to the yield by the expression[3] $t_{min} = 3.25W^{1/2}$ (same units). It is apparent on inspection of Fig. 3.3 that the EG&G expression would be a considerably better fit for the data than the AFSWP-503 expression. At this time, however, there are the following arguments for retaining the AFSWP-503 curve. The data used to derive the AFSWP-503 relation for yield and time to the minimum were based upon NRL bolometer (black body receiver with good time resolution) data from Operations GREENHOUSE, TUMBLER-SNAPPER, and IVY. Preliminary bolometer data from Operation CASTLE have also confirmed the AFSWP curve. When the spectral response of the instrument is limited, significantly different times to the minimum are observed.

1. The EG&G times to the minimum correspond to minimum emission in the visible, which is the sensitive range for the bhangmeter. Although the difference between bhangmeter times to minimum and bolometer times to the minimum should not be regarded as detracting from the value of the bhangmeter data, it does introduce a difficulty in correlating times to the minimum obtained with instruments having different or total spectral responses. The effect of spectral response was evident at CASTLE Shot 1, where EG&G found a progressive increase in times to minimum with filtered bhangmeters as the spectral response approached the blue as follows: 350 msec for red light, 450 msec for yellow light, and 650 msec for blue light. The black body bolometer time to minimum obtained by NRL was earlier even than that obtained with the red filtered bhangmeter, being 313 msec. It thus appears that in stating times to the minimum the instrument used in its determination must also be specified.

2. The NRL time to the minimum which was obtained spectrographically corresponds to

[redacted]

the minimum in black body temperature, which, if the entire fireball is in the field of view of the spectrograph, should correspond to the minimum in radiant intensity. Except for the times to the minimum for Shots 3 and 5, where the spectrographs viewed only a few square inches of the fireball surface, the NRL spectrographs saw a substantial proportion of the fireball. Thus the presence of spots, which are discernible in fireball photographs, probably was not a significant factor in the NRL results. Although a dead time of 2 to 3 msec is inherent in the NRL spectrographs due to zero time uncertainty, the values observed, as shown in Table 3.2, exceed this deviation from AFSWP-503. This is not to be considered final due to the preliminary nature of the NRL analysis of the spectrographic records.

3. The NRDL times to the minimum were obtained with radiometers, which have insufficient time resolution for the accuracy desired for study of weapons in the range of yields tested.

4. Since it has been indicated above that the spectral response of a sensing instrument has an effect on the time to the minimum, and since the AFCRC vacuum capacitor microphone is encased in a glass envelope, which is transparent only in the visual range, it is not surprising that the AFCRC times to minimum are different from those which would obtain with a bolometer. However, as with the bhangmeter, the microphone data are self-consistent, as may be seen in Fig. 3.3.

According to AFSWP-503, the time to the second maximum in radiant emission is related to the yield by the expression $t_{max} = 32W^{1/2}$, where t_{max} is in milliseconds and W is in kilotons. The data for times to the second maximum are given in Table 3.2 and are plotted in Fig. 3.4. It is seen that the AFCRC data scatter randomly about the line representing the above expression and agree within 10 per cent of the accepted values. Although the NRDL times fall within 10 per cent of the expression for t_{max}, it should be noted that the times all are greater than accepted values, the explanation for which lies in the lack of time response in the radiometers. A reason for the large scatter in the NRL data for times to the second maximum is not apparent. It is possible that in the more fully developed fireball which exists at the second maximum, discrepancies enter due to nonuniformity in shape of the source and to departure of the source from black body characteristics. Since fewer spectral data were reduced for times after 100 msec, due to the preliminary nature of the NRL analysis, there are uncertainties in the time of the second maximum of the order of ±25 msec. As will be seen from Table 3.2, some of the NRL data deviate from the AFSWP-503 curve by more than ±25 msec.

3.3.5 Energy Vs Time

NRDL data on the accumulated per cent of total thermal energy delivered as a function of time are plotted in Figs. 3.5 and 3.6 for Shots 4 and 9 and 10 and 11, respectively. The curves in these figures are useful in correlating the phenomena involved in the precursor. Although the accumulated energy vs time data have not been plotted for the other shots of this operation, satisfactory plots may be reconstructed through use of the generalized pulse in AFSWP-503.

3.3.6 Energy Normal to the Ground

In the study of precursor effects, the component of radiant energy normal to the ground is of interest. In Fig. 3.7 the data for the normal component of thermal energy are plotted for Shots 9, 10, and 11 of this operation, for the four shots of BUSTER, and for the first four shots of TUMBLER-SNAPPER. Using the curves in Fig. 3.7, curves of shock arrival time vs distance (such as Figs. 2.24, 2.25, and 2.41), and the curves of per cent thermal energy delivered vs time in Figs. 3.5 and 3.6, the energy normal to the ground prior to shock arrival may be calculated.

3.3.7 Thermal Layer

In a recent paper on the effects of irradiated surfaces on the generation of a precursor, Sauer[4] has analyzed air temperature, sound velocity, and thermal data from TUMBLER-SNAPPER. Whereas previously it had been thought that popcorning was the principal mechanism for transfer of heat to the air, Sauer's analysis indicates that the operation of conventional convec-

[redacted]

tive processes will probably satisfactorily explain transfer from the heated ground of most of the required energy into the air. Sauer also studied the case of the very high sound velocities over surfaces of fir boughs observed by NEL under Project 8.12a. Recent laboratory results from joint studies by NRDL and the California Forest and Range Experiment Station (CFRES) had indicated that gases initially evolved on intense irradiation of organic surfaces may contain elementary hydrogen. Since the observed NEL sound velocities were considerably higher than could be accounted for by any reasonable flame temperature and since the velocity of sound in hydrogen is four times that in air, Sauer has proposed a combination of convective heat transfer, flaming, and dilution with hydrogen gas as a qualitative explanation of the fir bough data.

DOE
b(3)
DNA
(b)(3)

3.3.8 [redacted]

Shots 3 and 6 were of particularly low yield, approximately 0.2 KT, and there is considerable current interest in the capabilities of weapons in this yield range. The thermal yield for an air-burst weapon of 0.2 KT yield extrapolated from curves based upon data obtained in the range 10 to 30 KT (AFSWP-503) should be about 0.097 KT [redacted]

b(3)
DOE

DNA
(b)(3)

3.4 CONCLUSIONS

Results of the basic thermal measurements of time to the second maximum and thermal yields are in good agreement with those calculated from the currently used scaling relations in AFSWP-503. Times to minimum in the thermal pulse were later than those predicted by AFSWP-503. It was concluded that this was due to the limited and different spectral response of the instruments used, thus indicating that when the time to the minimum is quoted the instrument must be specified.

Based upon results of the thermal measurements from this operation and from prior tests in Nevada, there is no further requirement for basic thermal measurements of weapons in the yield range 10 to 100 KT detonated in the air at lower altitudes. For air bursts of this type, presently available thermal scaling relations are sufficiently accurate for thermal effects studies with ground targets, under the ideal conditions prevailing at the NPG, provided the targets are located over suitably stabilized areas.

Further laboratory and field studies of thermal layers established over various types of surfaces (both organic and inorganic) are of interest. Such studies are under way in the laboratory at CFRES and at NRDL and in the field at TEAPOT. [redacted]

DNA
(b)(3)
b(3)
DOE

Further analysis of the thermal data obtained at this operation and from prior tests in Nevada appears to offer an attractive opportunity for evaluating the factors entering into the transfer of radiant energy through the quasi-ideal atmospheres in Nevada and through operationally more real atmospheres.

[redacted]

3.5 RECOMMENDATIONS

As a step toward relating the propagation of radiant energy through real atmospheres, it is recommended that all the thermal data accumulated by the various agencies from tests in Nevada be correlated and analyzed.

In order to extend or modify, as required, the present scaling relations for thermal phenomena in the yield range below 1 KT, it is recommended that means be found to disassociate the mass associated with the detonation of devices with yields in this range to the extent that the masses approach those contemplated for the stockpile weapons.

REFERENCES

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2. L. F. Drummeter, Jr., *A Method for Estimating Total Atmospheric Transmission of the Nevada Atmosphere*, Report NRL-4379, April 1954. CONFIDENTIAL
3. EG&G Staff, *Bhangmeter Mod II*, Project 12.1, Report WT-788, February 1954. SECRET RESTRICTED DATA
4. F. M. Sauer, *The Preshock Sound Velocity Field over Organic and Inorganic Surfaces*, Report AFSWP-420, December 1954, Division of Fire Research, Forest Service, USDA. SECRET
5. F. B. Porzel, *Preliminary Hydrodynamic Yields of Nuclear Weapons*, Report WT-9001, December 1953, LASL. SECRET RESTRICTED DATA

[redacted]

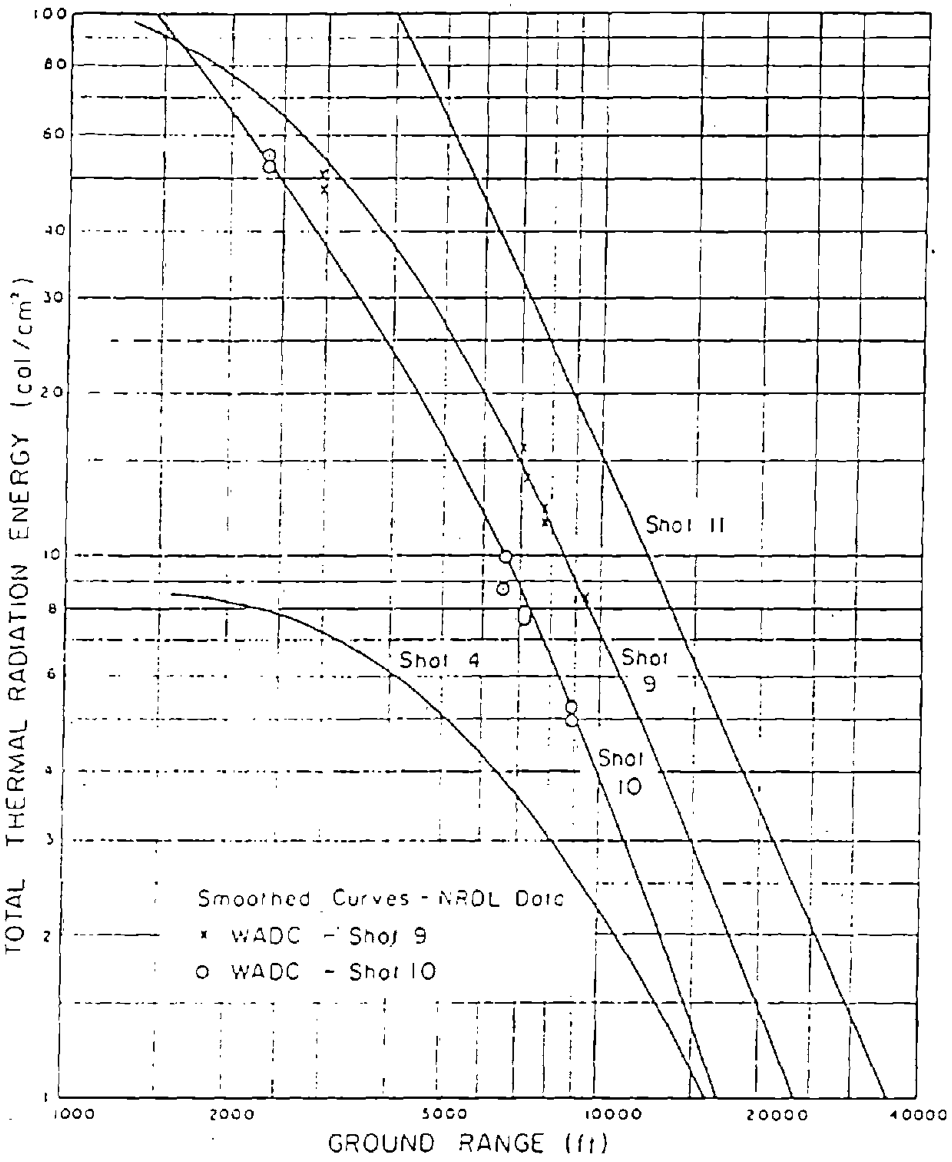

Fig. 3.1 — Total Incident Thermal Energy Vs Ground Distance (NRDL Data).

[redacted]

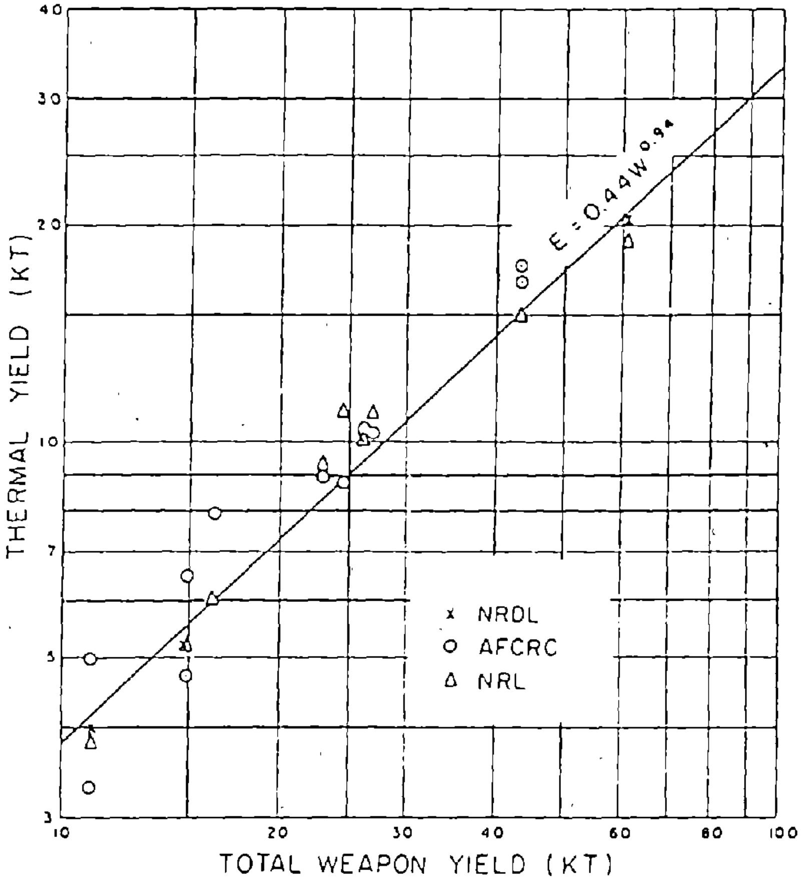

Fig. 3.2 — Thermal Yield As a Function of Total Weapon Yield.

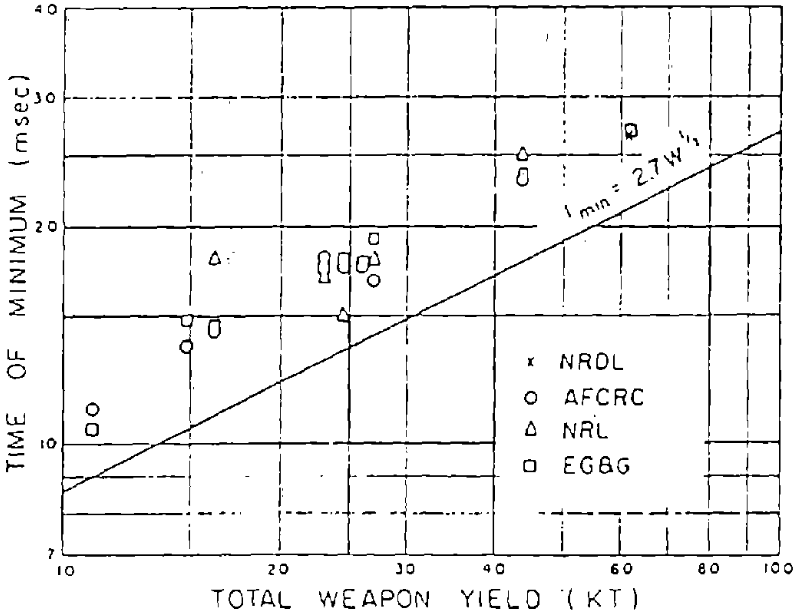

Fig. 3.3 — Time of Minimum Vs Total Weapon Yield.

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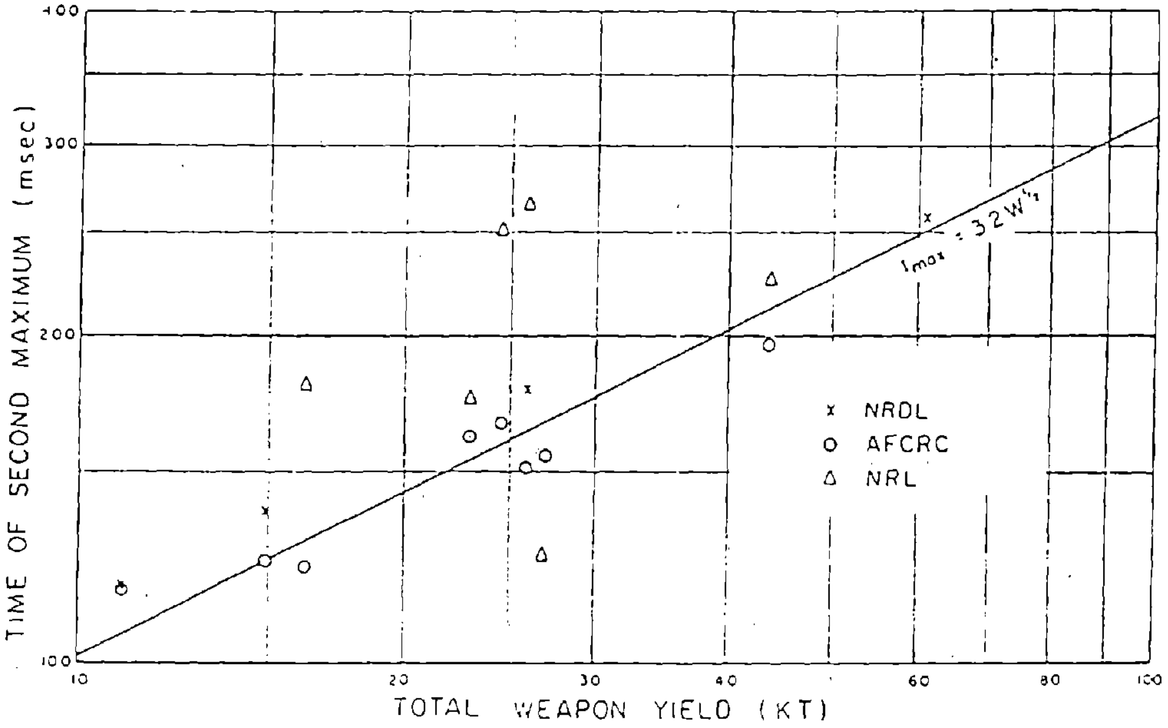

Fig. 3.4 — Time of Second Maximum Vs Total Weapon Yield.

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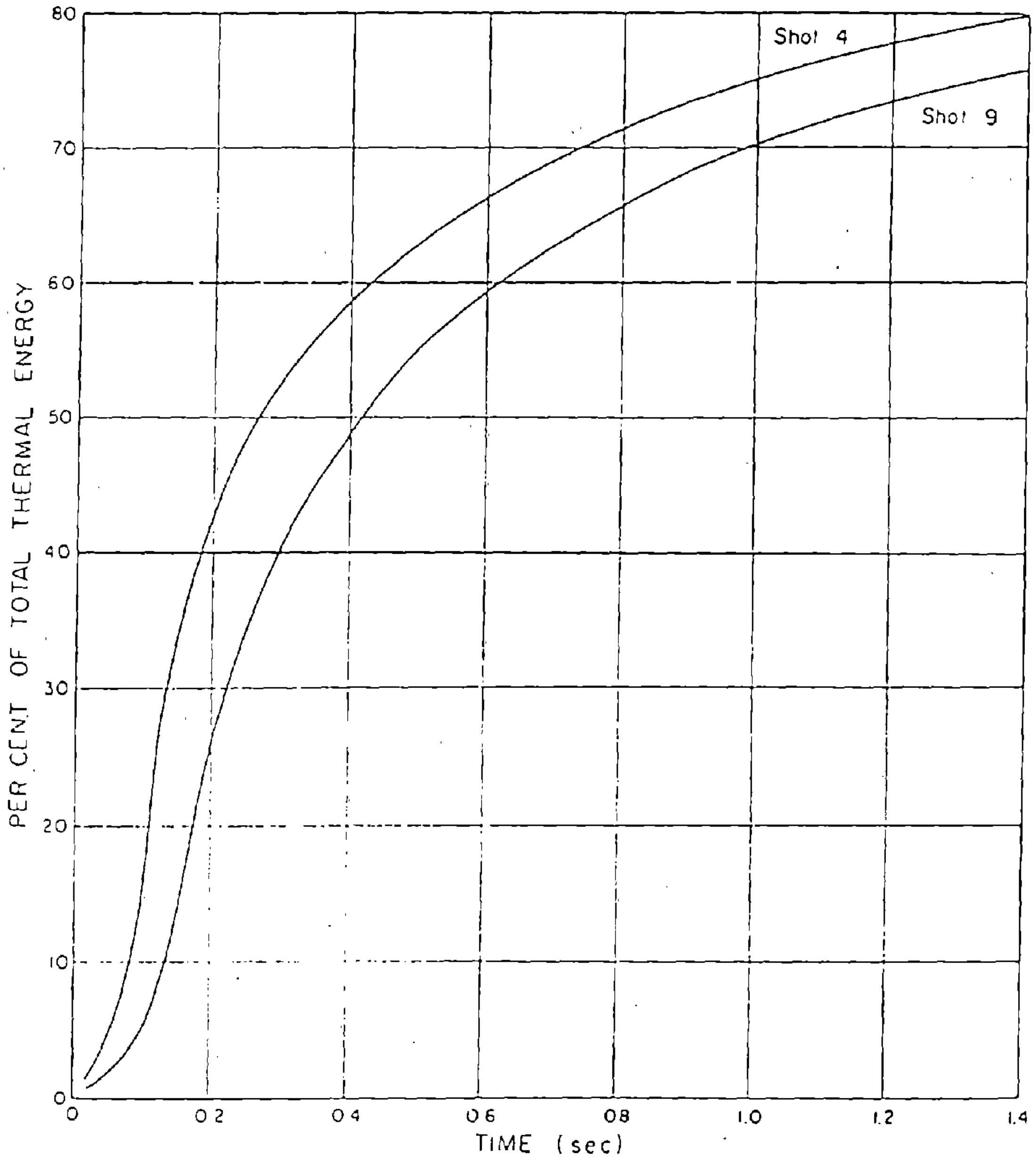

Fig. 3.5 — Percentage of Total Thermal Energy Vs Time, Shots 4 and 9.

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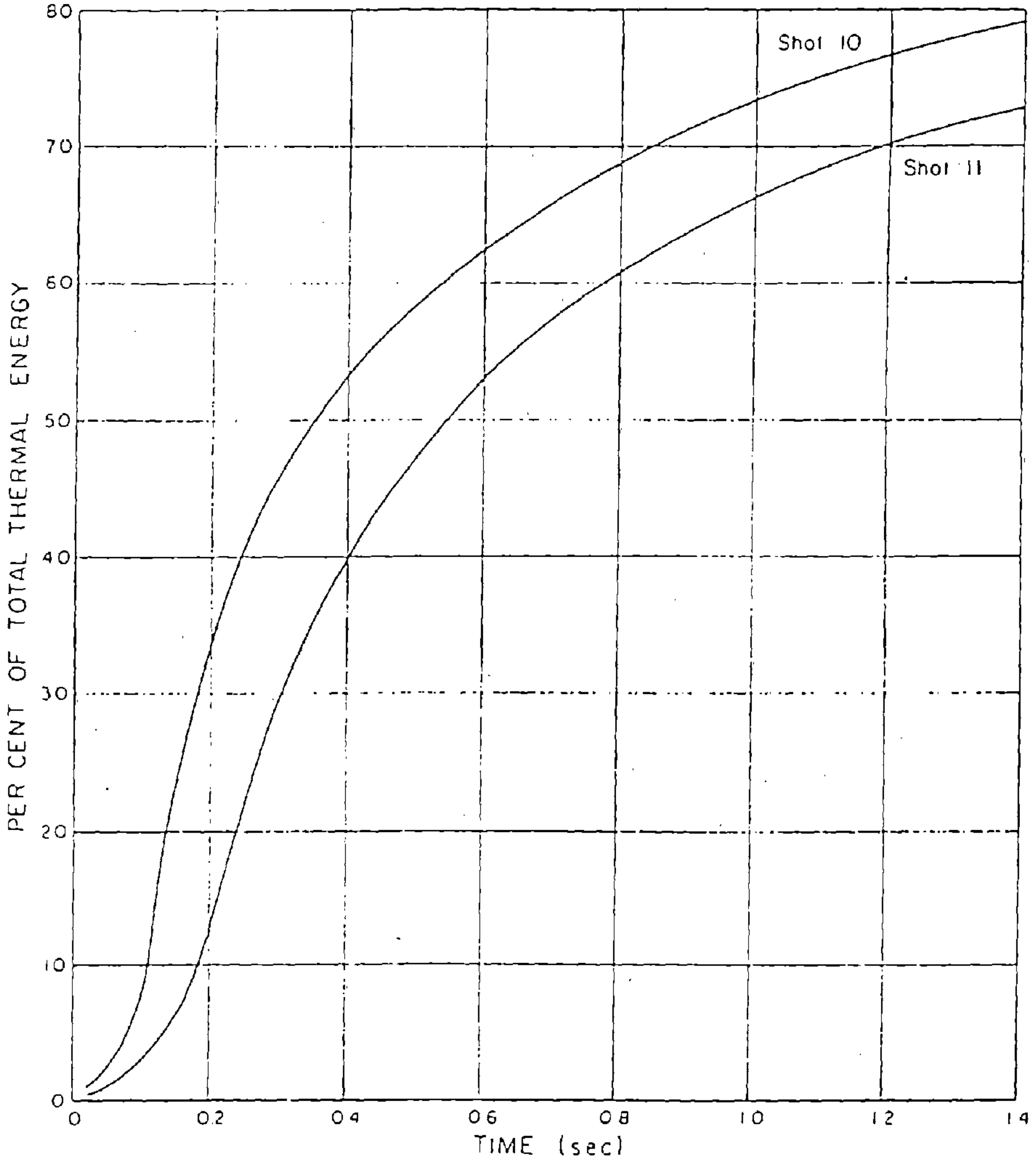

Fig. 3.6 — Percentage of Total Thermal Energy Vs Time, Shots 10 and 11.

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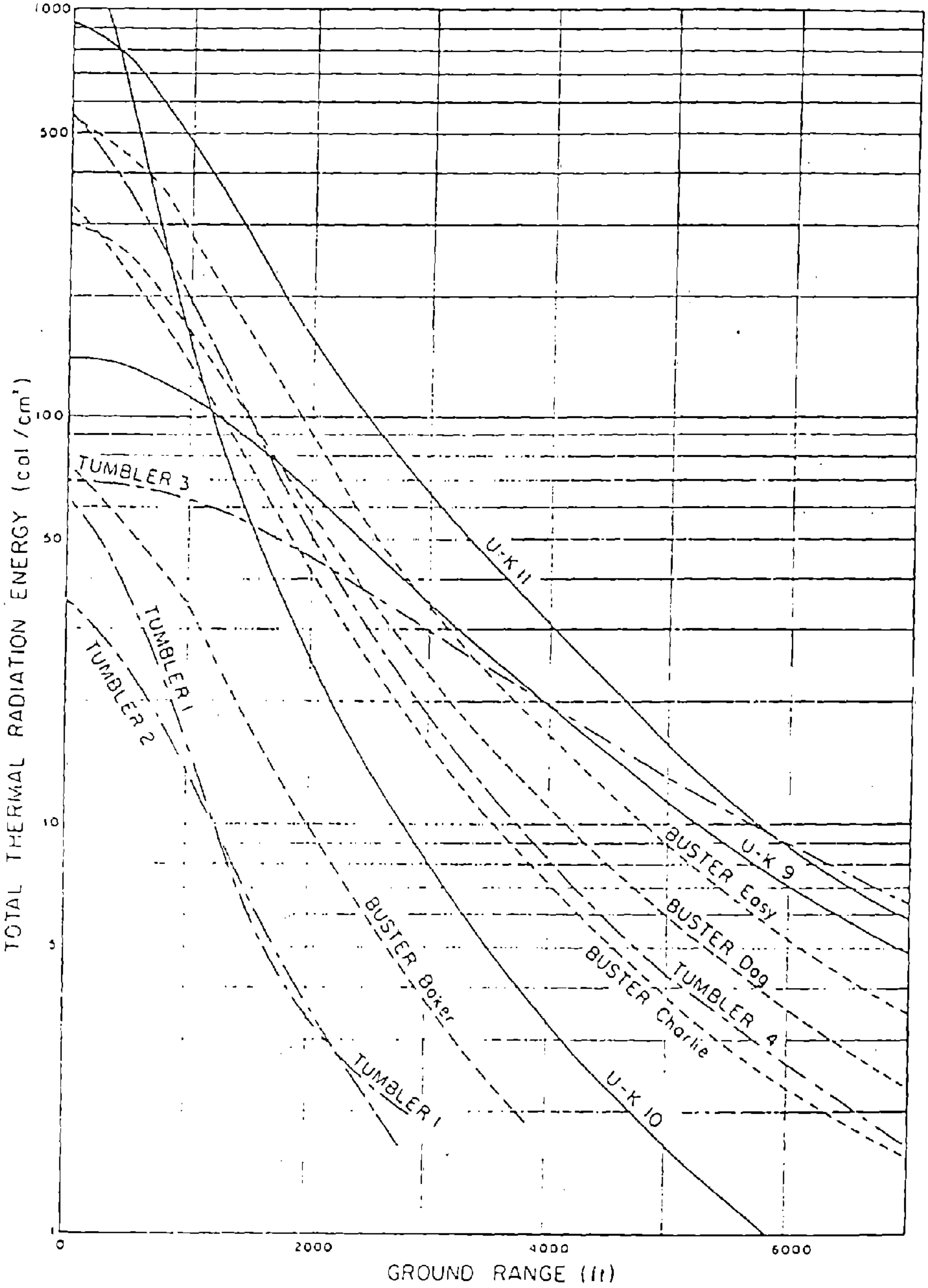

Fig. 3.7 — Thermal Energy Normal to Ground Vs Ground Range, BUSTER-TUMBLER-KNOTHOLE Series.

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the nuclear blast wave and calculating the response on a spring model of the mine.

The clearance of pressure-activated mines can be determined with very good accuracy from the static-response characteristics of the mines and the expected incident pressure waves. In precursor regions the pressures required to detonate mines will be the static pressures (about 13 psi for M6 and M15 antitank mines, and about 11 psi for the M14 antipersonnel mines). In regions of long-duration pressure waves and sharp shock fronts, the required detonation pressures will theoretically be reduced to one-half of these values (7 psi for the M6 and M15 and 6 psi for the M14). Since infinitely sharp shock fronts will never actually be realized, a more realistic value would be two-thirds of the static pressures; i.e., 9 psi for the M6 and M15 and 7 psi for the M14.

B.3.18 Project 3.19: Effects of an Atomic Explosion on Trees in a Forest Stand
Agency: U. S. Department of Agriculture
Report Title: Blast Damage to Coniferous Tree Stands by Atomic Explosions, WT-731
Project Officer: W. L. Fons

The objectives of this experiment were to: (1) determine the effects of atomic explosions on a stand of trees and isolated trees; (2) correlate experimental data with analytical methods of breakage prediction; and (3) study the shielding effects of a stand of trees upon the effects of an atomic explosion.

A stand of 145 ponderosa pine trees covering an area 160 by 320 ft was placed at approximately 6500 ft from Ground Zero. Isolated trees at 500-ft intervals in two radial rows 100 ft apart were installed from 5000 to 8000 ft. Tree pairs at each station were of substantially different periods. In addition a pair of trees was installed at 1500 ft, and a pair of pendulums at 5000 and 8000 ft. Average tree height was 51 ft and average diameter at the base was 15 in.

Instrumentation consisted of ground-level, 10-ft, and 60-ft pressure gages; pitot-type dynamic-pressure measurements; snubber-wire arrangements for the determination of deflections; accelerometers; strain gages; time-recording anemometers; and a wind-direction indicator. Still and motion-picture photography was also employed. See Fig. B.20.

Stations were located as follows:

	Shot 9		Shot 10	
Station	Distance from Actual GZ (ft)	Peak Dynamic Pressure* (psi)	Distance from Actual GZ (ft)	Peak Dynamic Pressure* (psi)
5000	4740	1.13	4850	0.30
5500	5240	0.90		
6000	5730	0.72		
6500	6230	0.58		
Stand	6460	0.52	6390	0.11
7000	6720	0.46		
7500	7220	0.37		
8000	7710	0.30	7850	0.055

*Computed from ground-level-measured, side-on pressure values.

On Shot 9 incidence of breakage of the isolated trees (31 out of 145) was about twice as great as predicted. No breakage occurred on Shot 10. The forest stand afforded complete thermal shielding beyond the fourth row of trees.

Close correlation between calculated and measured deflections for the isolated trees and between their predicted and actual breakage substantiates the generalized method of breakage prediction for isolated trees. Breakage and tree deflections within the stand were approxi-

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mately twice the value predicted on an isolated tree basis. Consequently breakage predictions based on isolated trees appear to underestimate the actual incidence of breakage for small forested areas. A postshot view of the stand is shown in Fig. B.21.

Within the limits of instrumentation there is apparently very little or no attenuation of peak overpressure, peak dynamic pressure, or their respective impulse in stands several acres in area.

Tree and pendulum deflections, dynamic pressure measurements, and the close correlation of deflection results on a dynamic-impulse basis indicate that greater damage to certain drag-type targets will accompany low burst heights at the Nevada Proving Grounds for pressure levels below that at which the precursor disappears and extending to overpressures of at least 1.5 psi.

B.3.19 Project 3.20: Vulnerability of a Typical Tactical Communications System to Atomic Attack

Agency: Signal Corps Engineering Laboratories

Report Title: Blast and Thermal Effects of an Atomic Bomb on Typical Tactical Communication Systems, WT-732

Project Officer: J. Eggert

The objective of this project was to subject selected items of Signal communications electronics equipment and material to air burst atomic weapons to determine the effects thereon.

Typical items of this equipment and material were exposed to blast, 93 test groups to Shot 9, and 17 to Shot 10. The test items included radial pole lines, transverse pole lines, separate poles without crossarms (both guyed and unguyed), 120-ft and 200-ft aluminum Signal towers, antenna systems, masts, buried and surface-laid wires and cables, and other items at various distances from Ground Zero. Several of the test items appear in Fig. B.22.

Reference should be made to the project report for a description of the test results, because of the vast number of individual items and the details of the different elements and the respective damage thereto. A brief description of damage to selected items is given here only as an indication of the nature of the [redacted]

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B.3.20 Project 3.21: Statistical Determination of Damage Criteria for Critical Items of Military Equipment and Supplies
Agency: Ballistic Research Laboratories
Report Title: Statistical Estimation of Damage to Ordnance Equipment Exposed to Nuclear Blasts, WT-733
Project Officer: E. Bryant

The objectives of this project were to obtain statistical data on damage to certain ordnance equipment and to use this information to verify methods of damage prediction.

The equipment exposed in Shot 9 consisted of twenty-seven ¼-ton trucks (Jeeps) (M38A1), twenty-seven 2½-ton trucks (M35), and two 90-mm AA guns (M1A1). For Shot 10, eleven ¼-ton trucks and eleven 2½-ton trucks, twenty-seven 57-mm guns (M1), five 105-mm howitzers (M3), seven tanks (M3, M4, M7, and M24), and two 90-mm AA guns (M1A1) were tested. The test items were in general oriented side-on, face-on, and rear-on to the blast. The guns and howitzers were tactically emplaced.

Instrumentation was provided to measure linear acceleration and angular velocity of several vehicles to determine their response. In addition, limited motion-picture coverage was provided for both shots.

The equipment was located as follows:

Test Items	Shot 9		Shot 10	
	Distance From Actual GZ (ft)	Peak Dynamic Pressure* (psi)	Distance From Actual GZ (ft)	Peak Dynamic Pressure* (psi)
¼-ton truck (M38A1)	875 – 6550	2.6 max 0.5 min	900 – 4380	126 – 0.5
2½-ton truck (M35)	875 – 6550	2.8 max 0.5 min	900 – 4380	126 – 0.5
90-mm AA gun (M1A1)	1500, 5200	1.7, 0.9	715, 3000	290, 1.9
57-mm gun (M1)			645 – 1240	430 – 4.9
105-mm howitzer (M3)			720 – 1265	290 – 36
Tank (M3)			1045	73
Tank (M4)			380 – 570	
Tank (M7-SP)			1415	23
Tank (M24)			715	290

*Estimated values.

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B.3.21 Project 3.22: Effects on Engineer Bridging Equipment
Agency: Engineer Research and Development Laboratory
Report Title: Effects on Engineer Bridging Equipment, WT-734
Project Officer: Capt V. S. Adkins, USA

The purpose of this test was to determine the effects of an atomic-bomb blast on military-type, prefabricated, fixed bridging. The specific objectives were to: (1) determine the loading due to blast; (2) determine the weakest structural component in the bridges, (3) determine what level of damage may be tolerated without causing progressive failure; (4) establish a general analytical method to calculate the response of truss structures to atomic-bomb blast; and (5) investigate practical methods of limiting the structural response of a Bailey bridge to blast loading.

Two 100-ft-span, double-truss, single-story Bailey bridges were tested, one in Shot 9 and both in Shot 10. In Shot 9, the bridge was free to slide except for frictional resistance developed at the support; for Shot 10, the bridge at the greater distance from Ground Zero was welded to supports to increase the deformation in the truss, and the nearer bridge was again free to slide except for frictional resistance. These were mounted on piers so that the bottom chords were about 22 ft above the ground surface. See Fig. B.23.

In addition, two single-bay sections of a Bailey bridge and a T6 bridge were exposed to both shots. They were placed on the ground surface, unanchored.

In order to determine experimentally the resistance offered by the frictional forces to the sliding motion of the bridge, a pull test was conducted on a bridge section. The skids and channels actually used later in the field test of the bridge, which was allowed to slide in Shot 9, were so tested. The static coefficient of friction was found to vary between 0.5 and 0.6, while the dynamic coefficient (velocity of bridge with respect to support was about 1 ft/sec) varied between 0.25 and 0.3.

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The results of the tests are summarized below:

Bridge	Shot	Distance to GZ (ft)	Peak Overpressure (psi)	Peak Dynamic Pressure (psi)	Average Rigid-Body Response (in.)	Remarks
100-ft Bailey	9	4100	7.75	1.52	43.5	No structural damage
1-Bay Bailey	9	1050	19.0	1.10		No structural damage
1-Bay T6	9	1050	19.0	1.10		No structural damage
100-ft Bailey	10	2000	10.6	>6	>240	Severe damage
100-ft Bailey	10	4250	4.1		*	No structural damage
1-Bay Bailey	10	1500	14.0		≈240	Severe damage
1-Bay T6	10	1500	14.0		≈120	Light damage

*This bridge was welded to supports.

For Shot 9 the 100-ft bridge was entirely within the Mach stem, so that the blast load was essentially horizontal. The ends of the bridge moved 30 in. and 57 in., or an average of 43.5 in. Skid marks indicate that there was no recovery, i.e. the motion was away from Ground Zero only. No plastic deformation was found in any of the bridge components. The single-bay sections of the Bailey and T6 bridges were also undamaged structurally, but were displaced as rigid bodies.

For Shot 10 the bridge at the greater distance, which was welded to the support, was undamaged. However, the bridge closer in was pushed completely off the piers. Evidence left by the skid marks indicate that the bridge was subjected to lift forces great enough to lift the windward side of the bridge from the support almost immediately and finally to lift a third corner of the bridge off the supports. Structural damage to the bridge was severe, but the direct effects of the blast cannot be separated from the effects of the 20-ft fall. See Fig. B.24.

The single bay Bailey bridge was moved about 20 ft and suffered severe damage to the components. The T6 bridge was moved about 10 ft and suffered only slight damage.

It was concluded that truss-type structures are drag sensitive; thus, predictions of damage should be stated in terms of dynamic pressure rather than peak overpressure, since dynamic pressure is not always uniquely related to peak overpressure. Damage from thermal radiation is not important for the size of weapon used in these tests.

Results from Shot 10 indicate that significant lift forces may be applied to bridges. Therefore a frictional-restraint anchorage alone is not satisfactory. An anchor cable that will give after a certain tension is reached appears to be a more satisfactory answer, and has the additional advantage that it can be connected to the bridge several feet out from the end, thus reducing the effective span.

The analysis indicates that the end-bay sway braces will be damaged before other components for single-story bridges of moderate or great spans. Rupture of the end-bay sway braces will, in general, result in the progressive collapse of the bridge. For double- or triple-story bridges, transom-clamp seats and rakers may be limiting factors, since their failure would allow the windward truss to lay over, thus causing collapse.

The sliding analysis of the bridge gave satisfactory results for the values of the parameters used.

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B.3.22 Project 3.24: Blast Effects on LVT's
Agency: Naval Radiological Defense Laboratory
Report Title: Effects of an Air Burst Atomic Explosion on Landing Vehicles Tracked (LVT's), WT-735
Project Officer: Lt Col M. R. Olson, USMC

The objectives of the test were to determine the degree of blast damage which LVT's would sustain from an atomic air explosion and to determine, qualitatively, the degree of protection which these vehicles afford from the effects of such an explosion.

Six LVT's were exposed to Shots 9 and 10 at various distances and orientations (see Fig. B.25). Dosimeters were installed on the exterior and in the interior of each vehicle to obtain data on gamma-radiation-dose-reduction factor for these vehicles. For Shot 10 only, the two most-remote vehicles were instrumented with four Taylor maximum-minimum thermometers and four sets of thermal temperature-indicating papers to indicate the temperature rise within the vehicles. Motion-picture coverage was obtained for one vehicle for each shot.

The vehicles were located as follows:

Vehicle Position	Shot 9		Shot 10	
	Distance from Actual GZ (ft)	Peak Side-on Pressure (psi)	Distance from Actual GZ (ft)	Peak Side-on Pressure (psi)
1	775	22.3	1030	52.0
2	935	20.3	1210	30.5
3	1705	14.0	1525	14.0
4	2410	11.1	1880	9.1
5	2420	11.1	2575	8.1
6	4510	7.1	3450	5.8

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B.3.23 Project 3.26.1: Test of the Effects on POL Installations
Agency: Air Materiel Command
Report Title: Test of the Effects on POL Installations, WT-736
Project Officer: B. J. O'Brien

The objective of this project was to study blast and thermal effects of an atomic detonation on gasoline and oil storage depots and on containers.

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Test items included in Shot 9 and Shot 10 consisted of three categories: (1) groupings of standard 55-gal. storage drums filled with diesel fuel; (2) storage tanks filled with diesel oil or aviation gasoline, especially designed so that the fuel would either seep or flow rapidly from the damaged tank; and (3) vertical storage tanks of either welded or bolted construction; the roof-section of the welded tanks was designed to model the roof action of prototype storage tanks of the 120-ft diameter class, while the bolted tanks represented standard Army equipment. The number of items is too large for individual listing here; however, the extreme ranges and corresponding blast and damage phenomena are given.

The test items were located as follows:

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B.3.24 Project 3.26.2: Effects of Atomic Weapons on a POL Supply Point
Agency: Quartermaster Corps, USA
Report Title: Tests of the Effects on POL Installations, WT-736
Project Officer: H. A. Stiles

The objective of this project was to determine the effects of an atomic explosion upon the following POL equipment: (1) cans and drums stored in the conventional manner for Quartermaster fuel dump; (2) cans and drums of gasoline protected by revetments, tie downs, and clamps; (3) collapsible gasoline storage tanks; and (4) can-cleaning equipment.

Each of the following items was exposed to Shot 9 at four different stations: (1) 55-gal. drums with and without protective cover, filled with gasoline or empty; (2) 5-gal. gasoline cans without protective cover, filled with gasoline; (3) two 900-gal. collapsible tanks filled with water, without protective cover, one of Marine Corps design and the other of Quartermaster Corps design; and (4) a 50-gpm pump circulating gasoline through a can-cleaning machine, without protective cover. A preshot view of the test items is shown in Fig. B.27.

The 55-gal. drums, 5-gal. gasoline cans, and a Marine Corps 900-gal. collapsible tank were retested in Shot 10, the first two items at three stations and the Marine Corps tank at a fourth station.

The locations were as follows:

	Shot 9			Shot 10		
Station	Distance from Actual GZ (ft)	Peak Side-on Pressure (psi)	Thermal Flux (cal/cm^2)	Distance from Actual GZ (ft)	Peak Side-on Pressure (psi)	Thermal Flux (cal/cm^2)
1	2600	11	68	750*	140	≈400
2	3150	7.6	38	1080*	40	≈250
3	6800	4.3	16	1590*	11	125
4	10,000	2.7	7	2160†	8	92

*Drums and cans only.

†900-gal. collapsible tank only (Marine Corps design).

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B.3.25: Project 3.26.3: Effects of an Atomic Explosion upon an Amphibious Assault Fuel Handling System (Shore Phase)
Agency: U. S. Marine Corps
Report Title: Tests of the Effects on POL Installations, WT-736
Project Officer: Lt Col H. W. Sharpenberg, USMC

The objective of the experiment was to determine the resistance of equipment and materials of an Amphibious Assault Fuel Handling System to thermal and blast damage of an atomic explosion.

Equipment and materials of an Amphibious Assault Fuel Handling System were selected for testing. The components of the system are LVT-transported fuel tanks, shore unloading equipment, shore transfer equipment, dispensing equipment, and storage equipment. Some of the test items were rigid-aluminum and collapsible-synthetic-rubber tanks, hose, pumps, meters, nozzles, strainers, etc. A typical array is shown in Fig. B.28.

The equipment was located as follows:

	Shot 9			Shot 10		
Station	Distance from Actual GZ (ft)	Peak Side-on Pressure (psi)	Thermal Flux (cal/cm^2)	Distance from Actual GZ (ft)	Peak Side-on Pressure (psi)	Thermal Flux (cal/cm^2)
1	2675	10.8	66	750	135	300
2	4700	6.6	32	1080	37	235
3	5585	5.1		1590	10.7	125
4	7825	3.6				
5	10,150	2.7				

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B.3.25 Project 3.27: Effects of Atomic Weapons on Field Medical Installations
Agency: U. S. Army Medical Field Service School
Report Title: Effects of Atomic Explosions on Field Medical Installations Equipment, WT-737
Project Officer: Lt Col E. S. Chapman, USA

The major objective of this project was to determine the effects of an atomic explosion on field medical installations, equipment, and personnel (as normally employed) and to determine the degree of protection which is afforded by placing such installations in dug-in positions.

Two types of composite field medical installations were displayed for Shot 9 at three distances from Ground Zero both in a standard aboveground position and in a dug-in position.

Unit Type A, a composite battalion aid station and regimental collecting station was established at Sites 1 and 2; unit Type B, a composite division clearing station, mobile army surgical hospitals, and evacuation hospitals, was established at all three sites. Each unit was established in the standard tentage authorized and contained all representative items of equipment authorized for those units. All of the equipment was arranged functionally within the installations and some of the equipment was operational at the time of the blast.

The location was as follows:

Installation	Distance from Actual GZ (ft)	Thermal Flux (cal/cm^2)	Peak Overpressure (psi)
1	4164	40	7.8
2	9000	8	2.7
3	15,000	1 – 2	1.0

Results of the test were highly satisfactory and demonstrated that casualty production and damage was severe at the most-forward site, moderate at the intermediate site, and mild to slight at the rear site. Pre- and postshot views are shown in Figs. B.29 and B.30.

Casualty incidence from all causes in medical installations of the types tested would have been about 98 per cent in both the above-ground and below-ground installations at Site 1, 10 to 27 per cent in the above-ground and 5 to 10 per cent in the below-ground installations at Site 2, and below 5 per cent for both types of installations at Site 3. At the site nearest to Ground Zero, the gamma radiation, thermal radiation, and burns from secondary fires would have contributed greatly to the high incidence of casualties. However, at the site furthest from Ground Zero, almost all of the casualties would have been due to flying missiles.

Medical-equipment maintenance personnel evaluated the key items of each site both before and after the blast. The general results of their study were:

Average Percentages of Equipment Undamaged or Repairable within the Unit

Unit	Site	Above ground	Below ground
A	1	50	25
A	2	95	100
B	1	64	55
B	2	66	96
B	3	99	100

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A comparative analysis at each site indicated that 30 to 50 per cent greater protection for personnel and approximately 40 per cent greater protection for equipment is afforded by having these installations dug in or revetted. However if fires should occur, the percentage of casualties and damage to equipment may be greater for a dug-in installation.

B.3.27 Project 3.28.1: Structures Instrumentation
Agency: Ballistic Research Laboratories
Report Title: Structures Instrumentation, WT-738
Project Officer: J. J. Meszaros

For the purpose of obtaining structural loading data in connection with Program 3 of Operation UPSHOT-KNOTHOLE, Project 3.28.1 was given the responsibility of measuring transient physical phenomena associated with the blast loading of specially designed structures and a variety of test items. On Shots 9 and 10, a total of 892 channels of instrumentation were provided to secure information on air pressure, earth pressure, structural strain, displacement, acceleration, panel-time-of break, and angular velocity. Projects instrumented were those of the Army, Navy, Air Force, and Federal Civil Defense Administration.

An electronic system based on referenced phase modulation was used as the principal method of instrumentation, in conjunction with Wiancko air pressure, earth pressure and acceleration gages, and Baldwin SR4 strain gages. Originally designed by the Webster-Chicago Corp. for use by the Sandia Corporation on GREENHOUSE, this equipment required considerable modification before being put into operation on UPSHOT-KNOTHOLE. Twenty-seven of these magnetic tape recording systems, each capable of supplying 20 channels of information, were needed for the number of measurements made. In this manner a total of 798 channels of information were provided, of which 703 yielded readable records; the remaining 95 were lost because of damage to some of the test items and electrical failures in the recording equipment.

Forty-three self-recording accelerometers designed by Engineering Research Associates were used as backup measurements for the Wiancko electronically recorded accelerometers. With a potential of 86 channels, these instruments provided 42 channels of readable data.

In addition to four panel break measurements made for the Federal Civil Defense Administration on Shots 9 and 10, displacement measurements were successfully attempted using two different types of self-recording gages.

To determine the extent to which certain structural members were strained beyond their elastic limits, 1152 measurements were made with a 2 in. Whittemore strain indicator.

From the results of this and previous tests of a similar nature, it is evident that an electronic system based on the recording of phase modulated signals on magnetic tape is feasible for this type of instrumentation. However, the present Webster-Chicago system should be improved upon in several respects. First, it is doubtful that the limited frequency response of such a system justifies its use, considering its cost and bulk; and the number of skilled technicians required to operate it. In addition to improving the frequency response, it would be highly desirable to provide a more linear playback system.

For future operations, it is apparent that a development program is needed to explore the potentialities of self-recording mechanical type gages and to investigate the development of an electronic system combining the flexibility of magnetic tape recording with the reliability and simplicity of the conventional 3-kc carrier type instrumentation.

B.3.28 Project 3.28.2: Structures Instrumentation
Agency: Naval Ordnance Laboratory
Report Title: Pressure Measurements for Various Projects of Program 3, WT-739
Project Officer: W. E. Morris

The Naval Ordnance Laboratory instrumented various Program 3 projects for pressure-time histories. The instrumentation system consisted of Wiancko inductance gages, FM intelligence generation, and magnetic tape data storage. Pressure measurements were made on three aboveground structures, one underground structure, five foxholes, a diffraction study

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layout around one of the aboveground structures, and a tree stand. The results of Shot 9 were excellent; 127 complete pressure-time records were obtained from the total of 128 stations instrumented. On Shot 10, forty-eight complete records and 48 partial records were obtained from the 105 stations instrumented. Broken cables caused by displacement of the structures accounted for most of the partial and total loss of records on this shot. The records were reproduced as pressure-time curves with pressure scales added and, along with instructions for record analysis and interpretation, were presented to the cognizant agencies for their analysis.

B.3.29 Project 3.28.3: Structures Instrumentation
Agency: Stanford Research Institute
Report Title: Pressure Measurements on Structures, WT-740
Project Officer: L. M. Swift

Project 3.28.3 of Operation UPSHOT-KNOTHOLE was concerned with the measurement of pressures existing on the surfaces of various nonresponsive structures from Shots 9 and 10. The experiment plan and the analysis of data were not a portion of this project, but the data were used in computation of structural loading and response under air blast. A secondary portion of the project was the definition of air blast conditions existing at the time of measurement.

A total of 143 satisfactory records were obtained from the two shots, a 99.3 per cent performance. Secondary air blast records were analyzed, and the results were published for the use of other projects.

B.3.30 Project 3.29: Tests of Four FCDA Curtain Wall and Partition Structures
Agency: Federal Civil Defense Administration
Report Title: Blast Effects of Atomic Weapons upon Curtain Walls and Partitions of Masonry and Other Materials, WT-741
Project Officer: B. C. Taylor

The objective of this test was to observe and determine the absolute and relative blast resistance of exterior and interior wall panels.

A group of continuous test cells were built with concrete floor slabs and reinforced concrete walls and roofs. Some idea of the cells may be obtained from Figs. B.31 and B.32. The front walls of three cells at the extreme right were used for panels under Project 3.5. The panels were 10 ft high and varied in length from 10 to 20 ft, the majority being 16 ft long; a large group contained steel sash. Test panels were installed on both the windward and leeward faces, and the cells also contained one or two interior partitions.

The exterior panels were reinforced concrete, reinforced and unreinforced brick, unreinforced cinder block, and various combinations of brick, clay tile, and cinder block. The interior partitions were cinder block, stud and plaster on metal lath, solid plaster, and removable steel. Various types of edge support were used.

Instrumentation included air pressure gages, displacement gages, and time-of-break gages on selected panels. In addition, the entire project was covered with 40 motion picture cameras.

This experiment was successful to the extent that the damage was substantially greater at the forward location than at the rear, permitting a bracketing of the range of pressure likely to damage much of the construction involved.

There was some additional damage due to Shot 10, mostly to rear walls where the front wall had been blown out previously, or to panels for which some damage had been noted after Shot 9.

Detailed evaluation of results has not been completed, but a few generalizations are possible. Walls with 20 per cent window openings (where the glass breaks) are much more blast resistant than walls without openings. Walls with these openings allow sufficient pressure to enter to wreck interior partitions of normal construction.

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B.3.31 Project 3.30: Air Blast Gage Studies
Agency: Ballistic Research Laboratories
Report Title: Air Blast Gage Studies, WT-742
Project Officer: J. J. Meszaros

The purpose of Project 3.30 of Operation UPSHOT-KNOTHOLE was to develop and proof-test self-recording gages for the measurement of pressure-time and peak pressure in connection with air blast waves from nuclear explosions.

To accomplish this purpose, prototypes were manufactured for three types of gages in quantities of 10 to 30 (see Fig. B.33). They were employed in numerous ways on several shots to determine their characteristics, limitations, and capabilities. A nylon and carbon paper initiation device was used on the pressure-time gages to start the recording disc at a finite time after the detonation of the device.

The pressure-time gages were accurate to ±10 per cent and recorded wave shapes very similar to those obtained by more expensive electronic instrumentation. The peak pressure gages were accurate to ±10 per cent, and no initiation device was needed.

The components of the gages tested form a basis for other gages to measure flow phenomena, underwater pressure, ground shock, acceleration, and temperature phenomena. It is concluded that gages of the type tested can give useful data, on tests requiring greater coverage and longer blast lines, with sufficient accuracy and for less expenditure of effort than is possible with other types of instrumentation.

B.4 PROGRAM 4 — BIOMEDICAL EFFECTS
Program Director: E. Pinson, Col, USAF

B.4.1 Project 4.1: Evaluation of the Hazard of Flying Through the Atomic Cloud
Agency: Air Force Cambridge Research Center
Report Title: The Radiation Hazard to Personnel Within an Atomic Cloud, WT-743
Project Officer: Capt P. M. Crumley, USAF

The general objective of Project 4.1 was to define and evaluate the magnitude and relative importance of the various potential hazards to which a flight crew in a modern pressurized military aircraft would be exposed upon flying through the cloud from an atomic bomb a few minutes after detonation. The specific objectives were to measure (1) the gamma radiation dose and dose rate by means of various dosimeters and ionization chambers carried through the cloud in parachute-borne canisters and in QF-80 (drone) aircraft, (2) the internal radiation dose due to inhalation of fission products received by monkeys and mice flown through the cloud in a ventilated pressurized compartment in these drone aircraft, and (3) the temperature, pressure variations, and turbulence in the cloud during passage of the drone aircraft. The planned procedure to attain these objectives was (1) to drop canisters through the cloud at +2 min when the cloud was at approximately 25,000 ft mean sea level (MSL) and at +8 min when the cloud had stabilized, and (2) to fly drones through the cloud at 30,000 and 32,000 ft (MSL), respectively, between +3 min and +7 min, the exact time of penetration being determined by the arrival time of the cloud at these altitudes. The most uncertain aspect of the operation was that of predicting the rate of rise and position of the cloud with sufficient accuracy to permit hitting it with the canisters and drones. Participation in three shots was planned, but weather conditions permitted participation in only two shots; namely, Shot 4 o [redacted]

Two of the canisters passing through the cloud at a [redacted] 9 registered a maximum dose rate of 7.5 r/sec and 10.6 r/ [redacted] on all other canisters were not obtained due to failure in hitting the cloud or to the malfunction of the telemetering equipment. Integrated radiation doses obtained by a film pack on each of four of the canisters hitting various parts of the Shot 9 cloud at the altitude and time stated above were 77, 120, 180, and 200 r. The latter value was obtained on a canister passing through near the center of the cloud. Since the canisters passed through the cloud vertically at a rate of only 150 ft/sec at this altitude, it is estimated that an aircraft traveling 400 knots and passing

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through the cloud horizontally at this time would accumulate a radiation dose between one-half and one-third that registered on the canisters. [redacted]

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One drone passing through the Shot 4 cloud a[redacted]showed a maxi- [redacted] an integrated dose of 11.3 r. A similar [redacted] showed an integrated dose of 29 r, the rate [redacted] in gave a maximum rate of 2.8 r/sec and an integ[redacted]e the visible cloud was not accurately known.

Although there is a factor of about two in the scatter of data, the combined GREENHOUSE and UPSHOT-KNOTHOLE experience on cloud and stem penetration at relatively early times suggests that the average dose rate in flying through an atomic cloud is independent of yield. For the time interval of 2.7 to 25 min after detonation, the data may be represented by $D = 1.31 \times 10^5 \times t^{-2.06}$, where D is the average dose rate in roentgens per hour and where t is the minutes after detonation.

The internal radiation dose to the lungs of a man due to inhalation of fission products during cloud passage in the three penetrations mentioned above amounted to an upper limit value of only 240 mr and, therefore, would have been insignificant both in actual amount and in comparison with the external dose received. It was shown that the alpha radiation hazard from unfissioned Pu^{239} and U^{235} and long-lived, bone-seeking fission products was also insignificant.

Temp tapes on the skin of the drones did not reach 65°C, the minimum recordable temperature during cloud passage. Pressure changes and associated turbulence of sufficient magnitude to endanger the crew or the aircraft did not exist in the cloud at the times of drone penetration on these tests.

The above results suggest that personnel in a pressurized aircraft flying at 400 knots or more which passes through the cloud of an atomic bomb of 30 KT yield or less at times greater than 4 min after detonation will receive a total external integrated radiation dose of less than 50 r. The internal radiation dose due to inhalation of fission products during such a passage is insignificant even when the air passing through the pressurized compartment is unfiltered and the crew members are not wearing oxygen masks. Any provision of filters in the aircraft cabin air intake or on the individuals' oxygen equipment appears to be an unwarranted precaution against an essentially nonexistent hazard.

B.4.2 Project 4.2: Air Blast Injuries
Agency: Naval Medical Research Institute
Report Title: Direct Air Blast Exposure Effects in Animals, WT-744
Project Officer: Capt R. H. Draeger, USN

Project 4.2 was designed to study direct air blast injury from atomic weapons in animals in the pressure range of 20 to 50 psi.

Two animal species of widely different sizes (rats and dogs) were selected in an attempt to compare levels of direct blast injury in small and large animals. It was expected that the comparative tolerances of such different exposure subjects to atomic air blast would help differentiate the roles played in blast injury by abrupt shock fronts and high peak overpressures as opposed to positive phase duration and impulse loading, whose relative importance was not clear from previous experience with high explosive (HE) blast experiments.

For test exposure purposes the animals were placed in 26-in.-diameter aluminum cylinders open at both ends in order to provide limited protection against missiles, thermal radiation, and ionizing radiation while permitting relatively free access to the air blast wave. Although it was realized that some attenuation of the external pressure-time relations might be expected to occur within the exposure cylinders, it was anticipated that actual measurement of the air pressure histories to which the animals were subjected would provide satisfactory data for analytical correlation. For this purpose small self-recording air pressure recorders whose action was initiated by a timing signal and which utilized sensitive diaphragm pressure detecting elements with a time resolution estimated to be approximately 4 msec were alongside the animals in a number of exposure cylinders.

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Two hundred rats were exposed to 24 to 30 psi overpressures in this manner on Shot 9, where the air blast physical measurements described clean cut blast waves approaching idealized shock wave form in the region of the biomedical blast exposure equipment. Autopsy findings showed moderate lung hemorrhage in most animals undoubtedly due to direct air blast, as the pathological findings were consistent with those seen after primary blast injury suffered from high explosive concussion waves in the laboratory.

On Shot 10, 700 rats and 56 dogs were similarly exposed. In the precursor region measured values of dynamic pressure were higher than those which would be calculated from measured values of peak overpressure using normal shock relations. The exact relations between the various parameters of the blast wave under precursor conditions have not yet been established. However, it appears that the measured dynamic pressures in the dusty region were at least equal to those which would have been predicted for low heights of burst over surfaces free of thermal effects. Due to drag forces many of the cylinders were displaced or damaged, and their contents were destroyed. Because of this and a further error of underestimating the effect of gamma and especially neutron fluxes received at the close-in distances of the biomedical cylinders, most of the animals were dead upon recovery (H + 4 hr), and those living were in a state of severe shock. Only 12 rats found scattered in the exposure area were recovered, and autopsy of these and of 50 recovered dogs revealed no trauma or lung hemorrhage indicative of direct air blast injury despite the rough treatment and high overpressures to which the animal specimens were subjected.

Examination of the pressure recordings taken within the cylinders and a review of pressure records made at equivalent ranges by other projects on Shot 10 confirmed the presence in that shot of a marked precursor pressure wave and of a slow rise time with serious perturbations of the idealized shock wave in the region of animal exposure. Peak pressures ranged from 105 psi at the innermost animal station to 16 psi at the outermost station on Shot 10.

Comparison of the pressure records and autopsy findings from Shots 9 and 10 led to the tentative conclusion that exposure to a pressure wave of slow rise time at a given pressure level under the conditions of blast exposure experienced in Shot 10 does not produce as much lung (blast) injury as the same peak pressure associated with an abrupt rise time, such as was experienced in Shot 9 and in experimental exposures to HE blast waves. However, a possibility that the more dramatic results of Shot 9 might have been due to a reflected pressure peak within the exposure cylinders could not be ruled out because of the low time resolution of the self-recording pressure gages placed in the cylinders with the animals.

B.4.3 Project 4.5: Flash Blindness
Agency: USAF School of Aviation Medicine
Report Title: Flash Blindness, WT-745
Project Officer: Col V. A. Byrnes, USAF

One objective of Project 4.5 was that of evaluating the efficacy of a filter system, which might be used as a lens in a sun glass or spectacles frame, for protecting the dark-adapted eye of man against retinal burns and reducing the time of flash blindness on exposure to an atomic-bomb flash. These filters have a negligible transmissivity for electromagnetic radiation of wave length less than 6000 Angstroms and more than 9000 Angstroms. Visible light is transmitted through these filters mainly in the red and orange region of the visible spectrum. Red-lighted cockpit instruments can be easily read through these filters. At the same time the filters, when worn, will reduce by about 75 to 80 per cent the energy in the combined visible and infrared region of the bomb spectrum which reaches the eye. When looking at the initial flash of an atomic bomb through these filters, burning of the retina may be prevented in instances where it might otherwise occur if the eye were not so protected. These filters also reduce the time of temporary flash blindness by about 25 per cent. For this latter purpose the filters appear less efficacious than for preventing retinal burns. Temporary flash blindness is associated with the bleaching effect of light on visual purple in the retina, a reversible chemical reaction. Reducing the amount of light entering the eye by means of the filters does not reduce proportionally the length of the time required for recovery of normal visual functions. Thus

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the filters are useful in reducing or avoiding retinal burns from atom bombs and are helpful in reducing the time of recovery from flash blindness.

Another objective of this project was to determine the threshold distance and/or thermal flux intensity which would produce a burn on the retina of dark-adapted rabbit eyes exposed to an atomic-bomb flash. Retinal burns were obtained in the eyes of rabbits exposed at distances from 2 to 42.5 miles from Ground Zero. The size and severity of the retinal burns obtained appeared to vary with the yield of the bomb and inversely with the distance of the animals from Ground Zero. The burn injuries to the rabbit retinae were assessed by clinical, photographic, histologic, and biochemical means.

Although differences in the physical and physiological factors between rabbit eyes and human eyes suggest that rabbits might experience retinal burns more readily than man, the data presented indicate that the retinal burn hazard of the bomb flash to man extends out to considerable distances. Retinal burns have been observed to occur in the unprotected eyes of man when exposed to the flash of an atomic bomb at distances up to 10 miles in SNAPPER and in an accidental exposure in UPSHOT-KNOTHOLE. That such burns may occur at greater distances is a distinct possibility. At distances greater than 10 miles the image of the fireball is small, and, consequently, the retinal area subjected to possible burning is small and likely of limited consequence in so far as impairment of vision is concerned, except in the rare instance where it might occur on the macula or area of central scotopic vision.

B.4.4 Project 4.7: Measurement of Beta Hazard in Bomb Contaminated Areas
Agency: USA, Office of the Surgeon General
Report Title: Beta-Gamma Ratio in the Postshot Contaminated Area, WT-746
Project Officer: Lt Col J. T. Brennan, USA

The objective of Project 4.7 was to determine the military significance of certain theoretical calculations based on idealized geometries which indicated that, in a bomb-contaminated area, the beta radiation dose to the skin should far exceed the gamma dose at all points in air less than about 2 meters above ground level. Because technical and theoretical considerations have mitigated against the feasibility of constructing a quantitatively accurate beta survey dosimeter for field use, it was felt that a direct measurement technique was required in order to determine whether current permissible radiation schedules and hazard control policies, based essentially on the measurement of gamma dose only, are acceptable.

The present experiment was designed to measure the beta and soft gamma radiation dose that would be received by the sensitive layers of skin that underlie the dead and unresponsive cornified outer skin surface always present. Measurements were made in several areas in Frenchman Flat and Yucca Flat contaminated by fallout from nuclear detonations form 4 hr to 40 days previously. Specially constructed ion chambers with thin walls designed to be equivalent in absorbing power to the epidermal layer of the skin were used to detect all beta particles and gamma rays that could penetrate to the sensitive layers of skin. These chambers were employed at various heights above ground in free air, and their readings were compared with readings similarly taken with conventional Victoreen chambers, whose thick walls discriminate against betas and soft gammas and allow an estimate to be made of the beta difference, which may be compared with the theoretical predictions. Chambers also were exposed in grooves along the sides of a masonite "phantom" of man to determine the shielding effect of man's body on the skin dose of soft radiations. Similar exposures with the chambers covered with thicknesses of conventional military clothing then demonstrated the protective effects of clothing against the beta and soft gamma flux. Further placement of chambers within shoes was designed to evaluate the protection afforded by shoes against the relatively high beta radiation expected near the ground surface.

It was found that although there is an increase in the radiation dose received by the thin-walled chambers in free air at points near the ground, the very large beta hazard predicted by theory does not actually occur in the field. The most probable explanation is that the theoretical calculations necessarily deal with a uniformly contaminated perfectly plane surface in which there is no masking of beta radiation by surface irregularities, whereas this is not the case in

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the field. Furthermore, some of the betas predicted by theory (probably a small portion) are soft enough to be absorbed in the walls of even the thin-walled chambers, although they presumably carry no beta hazard to the skin either. In addition, the walls of even the conventional Victoreen chambers allow passage of some of the more energetic beta rays, and they further allow passage of some Bremsstrahlung radiation, which is a reflection of the beta field. As a result of these latter considerations, the ratio of dose measured with the thin-walled chamber minus that measured with the conventional chamber divided by that measured with the conventional chamber (thin-thick/thick) will be less than the true beta-to-gamma dose ratio at the location of the measurements. The data showed a maximum soft radiation dose in free air near the ground about 5 times the dose measured with Victoreen chambers, and the effect of the man phantom was to cut this soft radiation dose to about one-half the free air value at any given height. The further protection of field clothing was on the average a factor of 2, whereas shoes protected by three or more times. The result of the decreasing soft radiation dose with increasing elevation combined with these protective effects located the point of maximum soft radiation hazard in the normally clothed man as on the lower leg just above the shoe top.

Because the erythema dose of skin for betas (or very soft gammas) is about three times the median lethal dose of gammas for humans, it was concluded that the maximum beta dose of two and one half times the gamma dose recorded with the use of the "naked" man phantom did not warrant the development of further personnel external radiation monitoring devices beyond the existing devices sensitive predominantly to gammas. This conclusion was further supported by the knowledge that in most actual field exposure conditions the additional protection afforded by clothing against betas and soft gammas would be present.

The conclusions drawn from this experiment apply only to the situation measured, namely, the soft radiation hazard in the air over a desert surface contaminated with fallout. Other geometries, such as city streets or ship decks, and other surfaces, such as metals or pavement, may give rise to higher ratios of soft radiation to hard radiation than are indicated by these data. Furthermore, this experiment in no way attempts to define the contact beta skin hazard that may arise when radioactive fallout particles fall directly onto the skin or are pressed directly against it, nor does it consider the problem of the relative hazards from hard and soft radiations emanating from a contaminated object removed from the fallout radiation field.

B.4.5 Project 4.8: Biological Effects of Neutrons
Agency: Naval Radiological Defense Laboratory
Report Title: Biological Effectiveness of Neutron Radiation from the Nuclear Artillery Shell in Free Air and in Foxholes, WT-747
Project Officer: Lt R. E. Carter, USN

Project 4.8 was designed to determine the biological effectiveness of neutron radiation from the gun type assembly nuclear device, detonated in Shot 10, both on the surface of the ground as a function of distance from the burst point and in conventional-sized foxholes as a similar function of distance.

Biological measurements were made on mice according to the techniques previously used at GREENHOUSE and TUMBLER-SNAPPER and included studies of organ weight loss, changes in the total white blood cell count, changes in the uptake of radioactive iron in erythrocytes, and determination of mortality as a function of time after exposure. Animals were shielded from gamma radiation by ventilated hemispherical lead shields of 7-in. wall thickness. Estimates by AFSWP indicate that animals within these shields may demonstrate 50 per cent or less of the neutron effect they would show had they been exposed to the neutron radiation from the weapon in free air. The attenuation of the biological effect by the lead shields may also vary with the neutron spectrum and hence with distance from Ground Zero. Animal exposure units were placed at varying distances from the indicated Ground Zero along the surface of the ground and also in foxholes, where the animals beneath the shields were positioned 42 in. below the ground surface.

Results indicated that the shielding afforded by the foxholes reduced the biologically recorded neutron dose by a factor of 3 as compared with ground surface measurements, but con-

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sideration of the role played by the lead shields suggests the foxhole protection factor may be significantly greater than 3. Satisfactory data were obtained for all biological parameters, both in the foxhole stations and in the stations on the ground surface. The value of rem per sulfur-measured neutron obtained from the artillery-shell device was lower than that previously obtained from similar animal exposures t[redacted]here rem was taken as "roentgen equivalent mamma[redacted]al indicators used. This suggested possible neutron spectral differences from the more conventional weapons over the distances studied, which was to be expected from the nature of the gun device.

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For the ground surface stations over the gamma radiation range of 100 to 800 r, the neutron radiation effect in rem, calculated with the assumption that the mice "saw" 50 per cent of the external neutron biological effect, appeared to about equal that of the gamma radiation dose in roentgens. The mean survival time of the neutron-irradiated animals was short (average of 3 days), and a relative protection of the bone marrow as compared with soft tissue structures was apparent. These findings are in keeping with previous observations.

In the foxholes neutron radiation appeared to be the dominant biological hazard at all distances of biological interest. Here the neutron radiation effect in rem, assuming that the mice inside the lead shield "saw" 50 per cent of the external neutron biological effect, appeared to equal about three or four times the gamma radiation effect to be expected in the bottom of these foxholes.

It was suggested by the project authors that although data obtained in this experiment and in previous experiments using the mouse have served as a valuable initial survey of weapon neutron radiation effect, large animal neutron studies are required in order to extrapolate animal data quantitatively to man, the point of ultimate interest.

B.5 PROGRAM 5—AIRCRAFT STRUCTURES TESTS

Program Director: K. H. Stefan, CDR, USN

B.5.1 Project 5.1: Naval Aircraft Structures

Agency: Bureau of Aeronautics
Report Title: Atomic Weapons Effects on AD Type Aircraft in Flight, WT-748
Project Officer: CDR K. H. Stefan, USN

The objective of Project 5.1 was to study the blast and thermal effects of atomic weapons on AD type aircraft in flight. Data covering weapons effects and airplane structural response to these effects were collected for the aircraft in level flight attitude, tail toward the blast in a vertical plane containing the burst point. This orientation represents an escape configuration of an AD type aircraft following delivery of an atomic weapon.

One or the other of two Navy Model AD's converted to drone configuration was flown on Shots 1, 2, 7, 8, and 9. The slant ranges at burst time involved in these shots varied from 14,400 ft for the AD-2 piloted flight of Shot 1 to 6200 ft for the AD-2 pilotless flight of Shot 7. In Shot 7 the actual yield exceeded the planned yield by greater than 30 per cent. The drone aircraft was positioned for near critical weapons effects, and the higher thermal radiation severely weakened all the blue painted skin on the underside of the wing. Both the port and starboard wing panels were torn off at the time of shock arrival as a result of the weakened skin and combined overpressure and gust effects. A considerable amount of valuable information on thermal damage was obtained from these panels, which were recovered after the test. Visual inspection of the structural failures indicated that the aircraft might have survived had the bottom skin of the wing been bare aluminum or painted with heat resistant white instead of standard blue.

In addition to the above flight tests, aluminum alloy panels of various thicknesses and paint finishes were exposed at three different stations on the ground during Shot 9 to obtain supplemental information on the effects of thermal radiation. Effective thermal absorptivity coefficients obtained ranged from 0.12 to 0.16.

Measured overpressures were in agreement with the theoretical values. Measured thermal radiation was observed to be appreciably greater than predicted as a result of ground re-

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flectivity. Thermal calculations using $\beta = 0.55$ (albedo) provided good correlation with test measurements. Peak aircraft accelerations were approximately double the calculated values, although measured wing and tail loads were in close agreement with the loads calculated using rigid body relations.

No direct correlation between measured and calculated aircraft skin temperature rise was established, although the effects of heat received, skin thickness, and surface finish were apparent. Results of metallurgical studies on aircraft skin specimens, begun in an attempt to determine skin temperature rise on Shot 7, indicated effects normally associated with temperatures far in excess of those recorded. This effect was so localized that no serious structural consequences in excess of those normally associated with the thermal intensities experienced are expected.

B.5.2 Project 5.2: Blast, Thermal, and Gust Effects of Aircraft in Flight
Agency: Wright Air Development Center
Report Title: Atomic Weapon Effects on B-50 Type Aircraft in Flight, WT-749
Project Officer: R. C. Lenz

Project 5.2 was established to determine minimum operational parameters for delivery of atomic weapons from medium bombardment aircraft. Three B-50D airplanes were selected and instrumented for the measurement of peak overpressure, thermal radiation, and wing tip deflection. One of the airplanes was further instrumented for the measurement of wing, fuselage, and stabilizer bending moments; angular and linear accelerations; and elevator positions.

A flight pattern was established so that the positions of the three B-50's simulated the position which would be occupied by a bomb-dropping airplane relative to the point of detonation of the weapon. Attainment of this position was confirmed by aerial mapping techniques from the test aircraft.

Gust loading of the horizontal stabilizer was determined to be the limiting structural parameter of the B-50 airplane for delivery of atomic weapons. The extent of this limit was closely defined by the attainment of 79 per cent of design limit bending moment at Station 98 of the horizontal stabilizer on Shot 9.

Sufficiently precise and extensive data concerning the effects of atomic weapons on the B-50 were obtained to enable accurate definitions of general operational parameters for delivery of atomic weapons with this airplane. In addition, the information is of such nature that it may be used in the correlation and correction of theoretical analyses which serve to extend the results to generalized problems of atomic weapon delivery involving other types of aircraft, positions in space, and other ranges of weapon yield.

Wing bending moments predicted on the basis of the current theoretical analysis were found to be consistently twice as large as the actual wing bending moments measured in this experiment.

B.5.3 Project 5.3: Blast and Gust Effects on B-36 in Flight
Agency: Wright Air Development Center
Report Title: Blast Effects on B-36 Type Aircraft in Flight, WT-750
Project Officer: G. F. Purkey

Project 5.3 obtained data on the blast response of a B-36D aircraft flown in the proximity of Shot 9. The test aircraft was the same B-36D aircraft utilized for similar testing by Project 6.10 during IVY. The instrumentation was modified to include additional measurements on the horizontal tail. Response measurements included nose, tail, wing tip, and center of gravity accelerations; wing fuselage and horizontal stabilizer bending moments; and horizontal stabilizer shear. Peak overpressure at the aircraft was also measured.

The purpose of the program was to supplement the blast response data obtained during the IVY tests and particularly to investigate more fully the aft fuselage and horizontal stabilizer response characteristics. The purpose was accomplished even though the peak loads obtained were not as high as desired. The peak stabilizer bending moment measured was 34 per cent

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of limit load. Peak wing bending moments were somewhat higher than those measured during IVY but were still only a fraction of the limit allowable. The data obtained by Project 5.3, combined with previous data, will allow a complete check of the present blast/load theory in the low and medium load ranges. Theoretical extrapolation to loads approaching design limit should be confirmed by additional experimental data.

The position of the aircraft at blast arrival was such that the reflected shock wave arrived 4.44 sec after the direct shock wave; and, because of fortuitous phasing with low amplitude vibrations initiated by the direct shock, the peak loads produced by the reflected shock were slightly higher than would be predicted from a single shock with the strength of the reflected shock. However, with proper phasing and shorter time interval between shocks, the reflected shock could induce peak loads considerably higher than those obtained from the direct shock.

The data obtained by Project 6.10 in IVY are included in the report of this project.

B.6 PROGRAM 6 — TESTS OF SERVICE EQUIPMENT AND OPERATIONS

Program Director: D. I. Prickett, Lt Col, USAF

B.6.1 Project 6.2: Test of Radar Techniques for Accomplishing IBDA

Agency: Wright Air Development Center
Report Title: IBDA Phenomena and Techniques, WT-751
Project Officer: F. E. James

The objective of this project was to evaluate current experimental techniques and equipment designed to accomplish Indirect Bomb Damage Assessment (IBDA). Specific objectives were as follows:

1. To determine the amount by which a radar beam is refracted by the fireball.
2. To compare the relative merits of Ku-band fast scan radar to Ku-band and X-band slow scan equipment.
3. To determine the adaptability of Airborne Moving Target Indicator (AMTI) equipment to the IBDA problem.
4. To evaluate a system of computing height of burst utilizing the time difference between arrival of a direct and ground reflected low frequency electromagnetic signal generated by the detonation and received in an aircraft.

The refraction experiment, conducted on Yucca Flat, utilized a main radar transmitter, 15 receiver stations, and a synchronizing radar station for remote control of the main radar transmitter. The receivers and synchronization station were located for each tower shot along a line perpendicular to a line from the main radar transmitter through the shot tower. The amount of refraction caused by the growth of the fireball was indicated by a shift of the main radar beam along the receiver line. It was determined that the amount of refraction was not significant and could be ignored in IBDA reduction procedures.

The fast and slow scan Ku-band radar, AMTI radar, electromagnetic receivers, and bhangmeters were operated from three B-29 aircraft oriented for each shot in the same relative positions to Ground Zero. The fast scan radar gave better time resolution to fireball return phenomena, but detail was lost due to antenna and power limitations. High interference levels prevented the obtaining of useful results with the AMTI equipment. The radar techniques tested, such as fast scan and AMTI, are all desirable and could probably be used in an IBDA system to assist in obtaining the required Ground Zero parameter. However, none of the techniques individually or collectively can be considered important enough to warrant the development of a special system for IBDA utilizing these techniques. When future bombing equipments include these techniques as part of their system, Ground Zero will probably be obtained with greater ease and accuracy than with the present AN/APQ-24 and K series bombing systems. The use of the electromagnetic wave is not considered practical for height-of-burst determination at this time. However, when more is known about the characteristics of electromagnetic pulse from an atomic detonation, further development and refinement of techniques might prove productive.

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B.6.2 Project 6.3: Field Test of IBDA
Agency: Strategic Air Command
Report Title: Interim IBDA Capabilities of Strategic Air Command, WT-752
Project Officer: Capt R. E. J. Scott, USAF

This project was a corollary to Project 6.2 in that an interim IBDA system, installed in operational SAC aircraft, was evaluated in connection with simulated strike missions. These simulated strike missions, flown by B-50, B-47, B-36, and F-84 type aircraft, also served to provide valuable and realistic indoctrination for SAC air crews.

Ten to 12 SAC aircraft participated in nine shots. Each aircraft carried current type radar bombing equipment and K-17 cameras. Several bhangmeters were also utilized. Photographic records and interpretation techniques employed by SAC show that they have satisfactorily developed an IBDA capability for determining height of burst and Ground Zero from the K-17C camera, i.e., photography during day or night visual conditions. Yield determination for this system can be obtained by utilizing bhangmeters. Their radar technique studies indicate that radar photography has the potential to supply Ground Zero and height of burst regardless of visibility conditions. The limiting factors are, for Ground Zero, adequate crew training in techniques; for height of burst, the yield and altitude combination must be such that there is adequate ground disturbance from the shock wave, and the cloud shadow effect must be discernible. Present stockpile weapons, if detonated at reasonable heights, should provide the necessary phenomena. The possibility of developing a technique to determine yield from radar records of the shock front or fireball growth time history are still under study by both WADC and SAC.

B.6.3 Project 6.4: Evaluation of the Chemical Dosimeter
Agency: Chemical Corps Chemical and Radiological Laboratory
Report Title: Evaluation of Chemical Dosimeters, WT-753
Project Officer: J. Johnston

The objective of this project was to evaluate, under field conditions, the E-1 tactical dosimeter, which is the latest version of the Taplin chemical dosimeter.

On Shots 7 and 8 a total of some 250 dosimeters were placed at eight separate thermal and blast shielded stations along the Project 6.8 dosimeter line at distances calculated to cover the entire range of the dosimeter. Results were evaluated against film exposed in National Bureau of Standards film holders. Dosimeters were recovered at H + 30 hr on Shot 7 and H + 2 hr on Shot 8. Field results combined with laboratory findings show that the E-1 dosimeters indicated within the correct range, were rugged, consistent, and showed little if any rate dependence. This dosimeter is considered to have reached its full state of development with the exception of mechanical and step range modifications.

B.6.4 Project 6.7: Electromagnetic Radiation over the Radio Spectrum
Agency: Signal Corps Engineering Laboratory
Report Title: Measurements and Analysis of Electromagnetic Radiation from Nuclear Detonations, WT-754
Project Officer: Lt W. T. Kertulla, USA

This project had two main objectives: (1) to determine the characteristics of electromagnetic radiation from nuclear detonations and (2) to determine the feasibility of detecting electromagnetic radiation from prenuclear detonations (Oxcart I).

Both experiments were performed primarily for information on scientific phenomena, with the knowledge that there exists practical military applications if any reliable characteristics can be systematically recorded and explained.

Results of previous experiments of related design have shown the 0 to 20 mc band to be the area of strongest signal return. Antennas, oscilloscopes, and related equipment were designed to permit evaluation of polarization, pulse amplitude, and time duration of the recorded signals in this low frequency band. The Oxcart I phase utilized pulse delay lines between antenna and

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oscilloscope, which, when triggered on a Blue Box, would record any prenuclear electromagnetic signals occurring immediately prior to the detonation.

The data when analyzed did not indicate any correlation between pulse characteristics, such as amplitude, duration, shape, etc., and yield. Neither did there appear to be any common characteristic which could be said to be typical of the pulse from a nuclear explosion. Polarization data were insufficient to determine a definite plane of polarization; however, the available data do not support the idea that the plane of polarization is vertical. No definite conclusions were drawn from the Oxcart I data obtained at Nevada; however, subsequent experiments with high explosives demonstrated that no HE signals of interest exist prior to the main nuclear signal because of their low signal strength and time resolution relative to the nuclear signal.

B.6.5 Project 6.8: Evaluation of Radiac Instrumentation, Equipment, and Operational Techniques
Agencies: Signal Corps Engineering Laboratory and Bureau of Ships
Report Title: Evaluation of Military Radiac Equipment, WT-755
Project Officer: J. M. Johnston

The purpose of this project was to test under field conditions the accuracy, reliability, practicability, and desirability of various service sponsored radiac instruments. These included rate meters and dosimeters, the majority of which were in the final developmental stage. In addition the project provided radiac instrument repair support for the Rad-Safe organization, film badges developing for Desert Rock, and instrument calibration facilities.

Radiac instruments were evaluated by conducting ground surveys in radiation fields up to 500 r/hr. Some 150 qualified service personnel were employed and rotated in weekly increments of 12 to 15 after attaining their maximum radiation exposure. Their comments, observations, and recorded data along with maintenance, repair, and modification records were utilized in the final evaluation of the instruments. In addition, numerous instruments were utilized by Desert Rock troops and by air crews of participating aircraft and their evaluation duly recognized.

Dosimeters were exposed in the prompt radiation fields of all shots. Some 12 to 14 stations located to cover the range of the dosimeters were utilized. These portable stations were designed with aluminum thermal and blast shields. All dosimeters were compared to film exposed in NBS film holders. The film standards were calibrated against a known calibration source of Co^{60}. Dosimeter readings were accomplished by numerous personnel, and results were cross-checked. All dosimeters were recovered about H + 2 hr, with the exception of one or two shots where fallout prevented recovery for several additional hours.

The two survey instruments of primary interest, the AN/PDR-32 and IM-71/PD, were found to require additional development and engineering work. The AN/PDR-32 models were preproduction units, and changes were recommended to improve the instrument before full-scale production is attempted. The IM-71 was found to require some development work, but, primarily, the IM-71 requires production engineering. It was recommended, however, that, following the development changes, preproduction engineered models of the IM-71 be procured and submitted for service testing by Army Field Forces. No further field testing of radiac instruments at NPG is warranted until preproduction test models, completely engineered, are available and have been accepted by the interested service laboratory.

The dosimeter evaluation indicated that two tactical and one administrative dosimeter have reached developmental maturity and are ready for final production engineering and package design. The DT-65 Polaroid and E-1 chemical tactical dosimeters were found to have reached an acceptable state of development, within the limitations of the device. If some difficulties with rate dependence and pressure sensitivity can be corrected, the IM-91 tactical dosimeter would be a good tactical dosimeter for service use. The DT-60 administrative dosimeter was tested on BUSTER. During UPSHOT-KNOTHOLE an attempt was made to evaluate the Admiral reader for the DT-60. It was found that the reader requires additional design and development work before being accepted. Some of these deficiencies had been corrected at the time of writing of the project report. One significant recommendation for future dosimeter testing is that more

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care be taken to evaluate the dosimeter accuracy in residual fields and that future dosimeter evaluation programs include a comprehensive analysis of dosimeter response to residual radiation fields.

B.6.6 Project 6.8a: Gamma Exposure Vs Distance
Agency: Signal Corps Engineering Laboratories
Report Title: Gamma Exposure Vs Distance, WT-756
Project Officer: Peter Brown

The objective of this report was to measure prompt gamma radiation as a function of distance. In addition, gamma measurements were made for any requesting project.

Data were obtained from film packs in NBS energy corrected film holders and were calibrated against a Co^{60} source. To obtain normalizing factors from a Co^{60} source to an atomic explosion, film was exposed to the Co^{60} field calibration unit and then to a 10 Mev betatron whose radiation spectrum is believed to approach that of an atomic detonation. Corrections for neutron flux effects on film badges were made for Shot 10 data out to 2000 yd from Ground Zero. Neutron flux effects on other shots were less than 5 per cent; therefore no corrections were made. No measurements were made on Shots 4 and 11, and Shot 2 data are felt to be low due to absorption caused by a concrete mass in the cab on the gamma line side of the tower. It is felt the results as presented in the 6.8a report are accurate to within ±20 per cent.

B.6.7 Project 6.9: Evaluation of Airborne Radiac Equipment
Agency: Bureau of Aeronautics
Report Title: Evaluation of Naval Airborne Radiac Equipment, WT-757
Project Officer: CDR J. H. Terry, USN

The purpose of this project was to re-evaluate Naval Airborne Radiac equipment which had been modified in accordance with BUSTER-JANGLE recommendations. This equipment was designed to record radiation levels above terrain, correct for variables, and permit rapid extrapolation to the ground for the plotting of ground contamination contours. In addition, new ideas in droppable flares, telemetering units, and flashing lights to indicate ground radiation levels were tested.

On all contaminating events a P2V aircraft with the permanently installed instrumentation made aerial surveys over the contaminated areas at H + 1 hr. Telemetering units were dropped on the evening of D Day and morning of D + 1 on three shots. Flares and flashing lights were tested at H + 1 on one shot only.

Results indicate that the airborne equipment functioned as designed, but operational techniques and equipment are much too complicated for the accuracy of the results obtained. Insufficient results were obtained from the flares, telemetering units, and flashing lights to make a firm conclusion, but the system of flares or flashing lights appears to be a practical approach to the problem of indicating high radiation levels on the ground from air observation.

B.6.8 Project 6.10: Rapid Aerial Radiological Survey
Agency: Signal Corps Engineering Laboratories
Report Title: Evaluation of Rapid Aerial Radiological Survey Techniques, WT-758
Project Officer: Lt J. R. Price, USA

This project had the objective of developing a system of estimating ground contamination from aerial survey by utilizing standard portable rate meters in light aircraft.

Standard portable survey meters were carried in both helicopters and fixed wing light aircraft. A clover-leaf pattern was flown over the contaminated area at H + 1 hr on all events having extensive contaminated areas. The flight pattern developed during JANGLE and SNAPPER was simplified and refined to permit a more rapid survey.

It was shown that ground contamination levels can be plotted from the air, using light aircraft and standard radiac survey equipment, with the results obtained being accurate within a factor of 10. No further work on this system is considered justified at this time.

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B.6.9 Project 6.11: Operational Training for TAC Crews
Agency: Tactical Air Command
Report Title: Indoctrination of TAC Air Crews in the Delivery and Effects of Atomic Weapons, WT-759
Project Officer: Lt Col J. W. Rawlings, USAF

The objective of TAC participation was to indoctrinate air crews in the problems of tactical delivery of atomic weapons and direct bomb damage assessment using aerial photography techniques. In addition, an attempt was made to obtain data on aircraft skin temperature rise utilizing temp tapes on the skin of the aircraft.

To indoctrinate the air crews, T-33 aircraft were positioned and flown to simulate recommended escape maneuvers. RF-80 aircraft were used to fly a standard photo reconnaissance mission to evaluate direct bomb assessment techniques.

Satisfactory indoctrination was obtained on one of the two shots in which TAC participated. The photo reconnaissance mission was performed satisfactorily, and photographic results were excellent for bomb damage assessment studies. The temp tapes were evaluated by WADC; however, no conclusive results were obtained since temperature rise was not greater than that which could have been caused by direct and reflected solar rays.

B.6.10 Project 6.12: Determination of Height of Burst and Ground Zero
Agencies: Army Field Forces and Evans Signal Laboratory
Report Title: Determination of Height of Burst and Ground Zero, WT-760
Project Officer: Lt Col R. V. Tiede, USA

With the advent of tactical support of ground troops by atomic weapons, the Army Field Forces indicated a need for a system to determine location and yield of nuclear weapons. The objective of this project was to evaluate the following systems in ability to fulfill this requirement:

1. Artillery sound ranging equipment for location of Ground Zero.
2. Seismic wave velocity determination of height of burst.
3. Flash ranging for location of Ground Zero and determination of height of burst.

Sound ranging stations were located up to 60,000 meters from Ground Zero. The system was comprised of three separate microphone arrays several miles apart along a line perpendicular to the line from the center of the array to the burst point. The sound ranging provided better results for air burst than for near surface detonations. For air bursts at ranges of 20,000 to 60,000 meters, an angular standard deviation of 13.8 min of arc and radial location error of 0.61 per cent were obtained. Calculation of the burst point required approximately 30 min after sound arrival.

Seismic geophones were operated approximately 8 to 10 miles from Ground Zero on all shots. An attempt was made to record a thermal induced seismic wave as well as the blast induced signal. Results were inconclusive.

Flash ranging cameras were located on a line roughly perpendicular to the lines of sight to the various Ground Zeros at a range of 8 to 12 miles. Pinhole cameras and Polaroid film were used to photograph the fireball. By triangulation from the surveyed camera locations, points of burst within an average accuracy of 0.75 miles were obtained; this required 5 to 10 min of calculation after removing the Polariod film from the cameras.

Conventional bhangmeters gave yields within 20 per cent to distances of 40 miles.

B.6.11 Project 6.13: Effectiveness of Fast Scan Radar
Agency: Navy Electronics Laboratory
Report Title: Effectiveness of Fast Scan Radar for Fireball Studies and Weapons Tracking, WT-761
Project Officer: R. B. Keeran

The objective of this project was to evaluate the effectiveness of a new developmental fast scan X-band radar for phenomenology studies of nuclear detonations and to attempt to track the 280-mm projectile.

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This Naval radar gave 20 antenna revolutions per second and provided excellent time resolutions for fireball shadow studies. The van-mounted equipment was tested on Shots 7 to 10. Presentation of radar return was made on a PPI and B scope and photographed.

The familiar "horse-shoe" shaped pattern was noted in some shots, whereas in others the pattern was missing, there being a complete blanking of all targets in the immediate area of the fireball. It was recommended that any future developmental radar designed for fireball phenomena studies have a higher bearing resolution of approximately 45° azimuth coverage and at least 50 scans per second.

Missile tracking on the gun shot was not possible due to the high ground clutter.

B.7 PROGRAM 8—THERMAL MEASUREMENTS AND EFFECTS

Program Director: R. G. Preston

B.7.1 Project 8.1a: Aircraft Structures Tests

Agency: Wright Air Development Center
Report Title: Effects of Thermal and Blast Forces from Nuclear Detonations on Basic Aircraft Structures and Components, WT-766
Project Officer: Capt G. T. James, USAF

The objective of this project was twofold. Primarily, it was designed as an integral part of the long-range WADC research and development program to establish design criteria for future atomic weapons delivery aircraft. The secondary, and more immediate, objective was to improve the state of knowledge pertaining to the delivery capability of present day delivery aircraft and to effect modifications to increase this capability.

The experimental procedure followed was to expose, at various ranges from Shots 9 and 10, basic and critical aircraft structures and components for obtaining their time history of temperature and strain responses. Specimens tested were 8 box beams, 8 tension ties, 13 horizontal stabilizer and elevator assemblies, and 6 aircraft panels. Additional measurements for peak temperature only were made on 31 aircraft panels, a B-36 stabilizer and elevator assembly, a B-36 wing section, 212 control surface protective coverings, and 89 undercarriage components.

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B.7.2 Project 8.1b: Aircraft Structures Tests

Agency: Wright Air Development Center
Report Title: Additional Data on the Vulnerability of Parked Aircraft to Atomic Bombs, WT-809
Project Officer: Capt G. T. James, USAF

This project was specifically aimed at the determination of the protection afforded parked aircraft exposed to atomic detonation by thermal radiation shields and strong tie-downs, and to

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obtain additional data on certain fighter and bomber aircraft in the nose-on orientation.

A B-17, B-29, B-45, F-86, and four F-47's, all of which had been used in previous tests except the B-29, were exposed in six shots for a total of 16 aircraft exposures. The instrumentation included extensive temperature determination on all exposures as well as considerable high-speed motion picture photography.

The more obvious conclusions obtained from this experiment were:

1. In those high overpressure regions where a relatively high degree of damage is sustained, strong tie-downs apparently reduce the amount of damage to fighter aircraft in the nose-on orientation.
2. Cloth thermal shields were observed to have provided protection from thermal radiation and thermal-blast coupling. It is anticipated that these shields will be far more effective protection against higher yield weapons where thermal radiation becomes relatively more critical than blast energy.
3. Data obtained in this test provide further confirmation of related data from TUMBLER-SNAPPER.

B.7.3 Project 8.2: Measurements of Thermal Radiation by Means of Radiation Pressure Phenomenon
Agency: Air Force Cambridge Research Center
Report Title: Measurement of Thermal Radiation with a Vacuum Microphone, WT-767
Project Officer: M. D. O'Day

The objective of this project was to evaluate a vacuum capacitor microphone as a device for measuring thermal radiation from the bomb. Signals generated in the microphone by the pressure of the radiant energy, which is related to the radiant intensity, are amplified electronically, fed to an oscilloscope, and recorded on magnetic tape. Overheating of the capacitor diaphragm by the incident thermal radiation is avoided by the use of a chopper operated at 1400 cycles/sec and, if the assembly is close to the detonation, by the use of neutral density filters interposed before the microphone. The amplitude of the output is related to the intensity of the radiant energy. Total thermal energies may be obtained by integrating the curves of intensity vs time.

Project 8.2 participated in Shots 1 to 10. The recording equipment was contained in two vans which were manned and located within view of the detonations. Sensing equipment was located at distances from 1 to 14 miles from the burst point.

As the result of the extensive participation of this project, a large amount of thermal data was obtained. Calculated thermal yields for this project correlate well with those of NRDL and NRL. Project 8.2 times to the minimum agree well with EG&G bhangmeter times (see Secs. 3.3.3 and 3.3.4).

Since the chopping rate of the vacuum microphone may be quite high, the instrument may be designed to yield values for times to minimum and second maximum in the radiant pulse. Further analysis of thermal yield data for this and past Nevada tests is necessary before the accuracy of the instrument for measuring thermal yield may be judged (see Sec. 3.3.3).

B.7.4 Project 8.4-1: Attenuation of Thermal Radiation by White Scattering Smoke
Agency: Chemical and Radiological Laboratories
Report Title: Protection Afforded by Operational Smoke Screens Against Thermal Radiation, WT-768
Project Officer: E. H. Engquist

The objectives of this project were dual: first, to evaluate the attenuation of thermal radiation by an operational fog oil smoke screen and, second, to collect data to verify theoretical predictions concerning the attenuation expected.

It was planned to conduct the field test of the white smoke (scattering smoke) on Shot 9. When it became necessary to delete the white smoke experiment at the last minute, due to unfavorable surface winds, a limited experiment using a single instrumented station surrounded by smoke pots was incorporated into Shot 10. Instrumentation for the attenuated ther-

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mal radiation employed NML roundels, NRDL disc calorimeters, Chemical Corps black ball calorimeters (these three types of instruments were arranged for detecting spherical dissymmetry), and photographic coverage for the determination of the volume-density characteristics of the screen.

As the result of the drastically curtailed experiment incorporated into Shot 10, the objectives of this project were only partially attained. Based upon the thermal energies measured beneath the smoke and after due allowance was made for the shielding of the scattering smoke by the Project 8.4-2 black smoke, interference by which was shown through analysis of the photographic records, it was estimated that the oil-fog smoke screen, as established, was attenuated by 85 to 90 per cent. Edge effects due to the limited size of the screen were not evaluated. Also, verification of theoretical predictions concerning the attenuation was not possible.

B.7.5 Project 8.4-2 Effects of Black Absorbing Smoke on Thermal Radiation and Blast
Agency: Chemical and Radiological Laboratories
Report Title: Evaluation of a Thermal Absorbing Carbon Smoke Screen, WT-769
Project Officer: E. H. Engquist

The objective of this experiment was to provide a relatively thick heated layer of air over a blast measurement line. This was accomplished by laying a carbon black thermally absorbing smoke over a line east of target zero for Shot 10 between 500 and 4600 ft from the target point. It was intended to study the effect of the heated layer on the shock wave, particularly the precursor pressure wave.

Instrumentation of the black smoke line was similar to that of the white smoke described in Sec. B.7.4 except that roundels were not used because they would be rendered useless by deposition of smoke particles on the energy sensitive papers. In addition to thermal radiation instrumentation, the smoke line was instrumented for blast and for the velocity of sound to measure air temperature. Two poles, one set at 2600 ft and the other at 3500 ft from intended Ground Zero, were equipped with shielded, temperature-sensitive papers at vertical intervals of 5 ft up to 72 ft in an additional effort to measure air temperature.

Due to the absence of a low capping inversion, which might have been attained with a shot time set for earlier in the morning, diffusion upward of the thermally absorbing smoke was greater than was desired for the comparatively low burst height for Shot 10. Ideally, it would have been desirable for the screen to have been capped strongly and uniformly at a height well below the height of the bottom of the fireball. In spite of this deficiency the shielding of the ground from significant thermal fluxes and the absorption of radiant energy in the relatively nonuniform smoke layer resulted in profoundly altering the shock front characteristics over those observed in the open.

The net effect of the smoke screen was to modify the precursor type wave under the absorbing layer and to reduce comparatively the range over which the precursor effect was observed in the open. The reduced thermal effect on the shielded ground surface resulted in peak pressures and arrival times of the shock wave more nearly like that which would be predicted for a thermally reflecting surface. At the instrumented stations between 2630 and 5630 ft from Ground Zero, the thermal energy observed was less than 3 per cent of that which would have been observed without smoke. Air temperatures in the screen at 2600 and 3500 ft ground ranges at heights up to 72 ft above the surface did not rise to the minimum detectable value of 60°C. At this height, however, it was calculated that the temperature rise should have been less than 1°C.

B.7.6 Project 8.5: Degree and Extent of Burns Under Service Uniforms
Agency: Quartermaster Research and Development Laboratories, USA
Report Title: Thermal Radiation Protection Afforded Test Animals by Fabric Assemblies, WT-770
Project Officer: J. F. Oesterling

The objectives of Project 8.5 were to obtain immediate information on the skin burn protection value of a limited number of service and experimental clothing combinations, and to

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provide data which can be used to establish a relation between fabric protective characteristics as determined in the field and protective characteristics as measured in the laboratory. It is anticipated that the results of these experiments, coupled with results of related laboratory programs, will lead to the development of a technique whereby the protective value of clothing may be assessed by physical means directly in the laboratory without resorting to physiological experiments or field tests.

In order to accomplish the above objectives, two types of animal exposure were made. In the major effort animals were exposed to the thermal pulse and ensuing blast wave in clothing of standard or experimental armed services uniforms. In the other case animals were exposed in cylinders provided with fabric-covered portholes, which duplicated the exposure arrangement used in the laboratory.

Of the several summer and winter uniform assemblies evaluated at Shots 9 and 10, two exhibited substantial degrees of protection, one of which assemblies, the four-layer temperate, provided protection against thermal burns up to 83 cal/cm^2. Fire resistant combinations were superior, especially at lower thermal energies, to untreated fabric assemblies. Increased fabric spacing (loose-fitting) and greater number of fabric layers contribute significantly to higher degrees of thermal protection afforded by uniforms.

Based upon the field and laboratory studies of protection afforded by uniforms against thermal burns, it is considered that attention in future laboratory studies should be devoted to spacing and fitting of garments, to mechanisms of heat transfer through fabrics as it affects burns to the underlying skin, to effects of pulse duration (weapon yield) on burns, and to effects of the subsequent arrival of the shock wave in snuffing out flame and removing glowing outer fabric layers.

Considering as a whole the results of this project and the related results of Projects 8.6 and 8.9, it is concluded that significant progress has been made in the evaluation of protection offered by fabrics against thermal burns and in delineating the factors to consider in the development of physical methods for the evaluation.

B.7.7 Project 8.6: Thermal Effects on Clothing Materials
Agency: Quartermaster Research and Development Laboratories, USA
Report Title: Performance Characteristics of Clothing Materials Exposed to Thermal Radiation, WT-771
Project Officer: J. F. Oesterling

The objectives of Project 8.6, which were closely associated with the animal exposure experiment (Project 8.5), were:

1. To determine field performance characteristics of standard armed services clothing and experimental fabric assemblies by means of panels exposed to the thermal radiation of a nuclear weapon.

2. To relate the data thus obtained to that developed through the field exposure of clothed pigs (Project 8.5).

3. To determine whether or not flaming may occur between the end of the thermal pulse and the arrival of the blast wave.

4. To utilize these data in establishing laboratory evaluation methods which can be used as screening techniques for determining the relative merits of protective fabric assemblies which may be used in the development of combat or field uniforms.

In addition, certain items of equipment of interest to the Chemical Corps and certain packaged materials, which are not amenable to laboratory study, were exposed to both thermal radiation and blast in order to obtain field evaluation of the resistance of the materials to the effects of a nuclear detonation.

The effectiveness of the protection provided by the various panel materials was estimated by means of the temperature reached on the panel backing as determined by passive temperature indicators. The effect of the presence of an air space between the backing and the material was also studied.

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Results from the panel experiments with the same fabric assemblies as were used with the pigs (Project 8.5) indicated a ranking of the fabrics, with respect to degree of protection, the same as that obtained with the clothed pigs. Other fabric combinations not tested with the pigs were ranked as to degree of protection from the results of the panel tests.

No conclusive results were obtained from panel tests designed to study the effects of fabric reflectance and spacing. It was concluded that destruction of the outer layer in a large proportion of the test samples introduced the factor of glow and sustained exothermic reactions which complicated analysis of the results.

Although results of panel tests on the effects of flaming and sustained glowing of irradiated fabrics led to no quantitative conclusions, the results indicated definitely the beneficial effect of using an outer fabric layer treated with a fire retardant agent.

The effect of the area of fabrics exposed in contact and spaced from the backing indicated that areas of the order of 1 or 2 in. in diameter, closer to the latter for spaced fabrics or multiple layer combinations, are necessary to avoid excessive edge effects from smaller exposure areas. Results from tests at Shot 10 of Quartermaster items of packaged rations and clothing indicated damage to be attributable primarily to blast effects. A single bale of clothing exposed to 12.5 cal/cm^2 was consumed by fire. The origin of the primary ignition in this case was not evident.

The test results of other Quartermaster items and Chemical Corps items were essentially as expected.

The ranking of fabric combinations with respect to protective characteristics was accomplished in this project by instrumenting oak veneer backing with temperature indicators (paper thermometers) adhered to the exposed side of the backing. These papers served to indicate the maximum temperature attained by the system comprising the surface of the backing and the paper. It should not be presumed that the temperature attained with the papers (and the ranking of the fabric) bears a relation to degrees of burns to skin. The National Bureau of Standards has shown, theoretically, that the temperature indicators have properties which prevent their thermal behavior from simulating that of human skin. For this reason, the results of this project, except for the exposure area studies, should be interpreted with caution. As is noted in Sec. B.7.8, the status of physical methods for evaluating fabric protective qualities is unsatisfactory at the present time; and it appears that a reliable physical method must await the development of an improved skin simulant.

B.7.8 Project 8.9: Effects of Thermal Radiation on Materials
Agency: Naval Material Laboratory
Report Title: Effects of Thermal Radiation on Materials, WT-772
Project Officer: T. I. Monahan

The general objective of this experiment was to obtain field checks of material damage studies currently being conducted in the laboratory with a simulated radiant energy source of small size. Of interest was the establishment of check points for cloth–skin simulant studies, for material damage as a function of the variable time–intensity of the energy from the bomb, for evaluation of temperature-sensitive passive indicators behind clothing, and for evaluation of certain material parameters influencing the protective value of fabrics and paints.

The development of a purely physical laboratory method for evaluating the protection offered by clothing is an objective which, if attained, would be of considerably wide interest. With the present state of the art, experimentation to evaluate clothing with animals in the laboratory is difficult and expensive when compared to a physical method. It has been shown that burns on skin behind cloth barriers cannot be correlated with damage to the cloth. It has also been shown that the shape and amplitude of time–temperature curves obtained on the skin surface upon irradiation are rough indications of the degree of burn. The NML experiments on plastic skin simulants behind cloth employing thermocouples were designed to utilize the latter fact.

It has been demonstrated that thermal damage does not follow a reciprocity relation as the time of delivery is indefinitely decreased for the same total energy delivered. The radiant energy necessary to effect an observed damage, i.e., the critical energy, however, is a useful

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quantity for correlating such effects. In the NML experiment thermal damage as a function of the period in the period of radiant emission during which sensitive materials were exposed was accomplished by a calibrated spring-loaded cover which traveled down a slotted frame and successively exposed and covered up the materials once the cover was triggered by a zero time signal.

The time—temperature histories of the polyethylene skin simulant with various cloth barriers in contact with the simulant irradiated in the field were only in fair agreement with laboratory tests. It was found that the area of cloth exposed becomes important as spacing of the fabric from the backing is increased, important with multiple layer systems and important where flaming of the outer layer occurs.

Temperature-sensitive papers attached to polyethylene skin simulant show little promise as a tool for evaluating protection offered by cloth barriers. Temperature-sensitive plastics painted on the polyethylene show some promise for gross-ranking of the protective qualities of fabric (see Sec. B.7.7.)

Due to partial failure of equipment at shot time, insufficient data were obtained from the devices which exposed materials either to the initial or latter portion of the thermal pulse. Consequently, no quantitative conclusions, based upon field results, could be made concerning the failure of reciprocity for thermal damage. However, with the shaped thermal pulse simulators now available at NML and NRDL, loss of the field data should not materially hamper thermal effects studies.

Although the time—temperature histories of the polyethylene skin simulant were in fair agreement with NML laboratory tests, a recent AFSWP review of the status of the skin simulant studies indicates that the polyethylene is significantly lacking in the desired characteristics of a simulant. Increased emphasis is planned toward development of materials which will more closely simulate the conductivity, absorptivity, and heat capacity of human skin. Results from recent work at NML with other simulants are encouraging.

B.7.9 Project 8.10: Measurement of Basic Characteristics of Thermal Radiation
Agency: Naval Radiological Defense Laboratory
Report Title: Physical Characteristics of Thermal Radiation from an Atomic Bomb Detonation, WT-773
Project Officer: A. Guthrie

The objectives of this project were to supplement definitive information on the basic thermal radiation phenomena associated with small yield weapons (below 100 KT) for extension and corroboration of scaling laws and effects prediction methods, and to provide documentation of the radiant energy characteristics of Shots 9 and 10 for use with the large effects test program. The NRDL calorimeters and radiometers employed by this project are considered the basic instruments for effects test studies of thermal radiation.

Any instrument employed to measure thermal radiation which has a finite field of view always receives, in addition to direct collimated radiation from the bomb source, some energy scattered from the atmosphere. Any instrument which sees, in addition to the fireball, any portion of the ground below the burst point receives energy over that coming directly from the fireball through ground reflection.

It has been demonstrated, qualitatively, that, at a given point in the air above the ground in the vicinity of the burst point, the radiant energy received at that point may be substantially in excess of that predicted from the inverse square relation. The albedo (or scattering coefficient) of the ground and the specific geometry of the burst point with respect to the ground and the point of interest in space are factors which influence the enhancement of the radiant energy.

In order to obtain the necessary field data for checking theoretical approaches to the problem of calculating scattered radiation, ground stations at Shots 4, 9, 10, and 11 were generously instrumented with field-of-view, air-scatter, and albedo calorimeters as well as total energy calorimeters directly viewing the fireball. In addition, at Shots 4 and 9, two SAC B-50 planes flying formation with the drop plane were instrumented with calorimeters for albedo and total energy determinations.

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Limited instrumentation for total energy and spectral distribution was accomplished under this project for the black and white smoke patterns under Project 8.4.

At Shot 10, special efforts were made to instrument two ground stations with both NRL and NRDL calorimeters so that direct comparisons of results could be made.

Measurements under this project were also conducted at Shot 3; but since the weapon went far below the anticipated yield and due to failure of some of the recorders, no reliable data were obtained. Other than the failure of the instruments on Shot 3, all instruments functioned satisfactorily, and essentially all channels gave useful information.

The thermal yields calculated from the measurements of this project agree closely with those in AFSWP-503. Due to inherently slow time resolution, times to minimum as measured with NRDL radiometers are greater than those calculated from AFSWP-503. Times to the second maximum suffer similarly but to a lesser extent.

The large quantity of data on reflection and scattering of radiation which were obtained by NRDL at this operation and at TUMBLER-SNAPPER is yet to be analyzed.

B.7.10 Project 8.11a: Initiation and Resistance of Primary Fires (Structures and Interior of Structures)

Agency: Forest Products Laboratory, Forest Service, USDA
Report Title: Incendiary Effects on Buildings and Interior Kindling Fuels, WT-774
Project Officer: H. D. Bruce

Both this project and Project 8.11b were concerned with the study of urban vulnerability to primary ignitions resulting from the radiant energy of atomic weapons. The probability that mass-fires, fire storms, and conflagrations will occur following an atomic attack on urban areas depends to some extent upon the frequency of occurrence of the primary ignitions. Methods for predicting the frequency of ignitions are important in making target analyses for offensive and defensive military operations. Studies under this project were devoted to kindling fuels found either as a part of a combustible building itself or found within a building. Studies under Project 8.11b were devoted to kindling fuels found exterior to buildings.

Kindling fuels which are commonly encountered in American cities were known to the two Forest Service groups conducting Projects 8.11a and 8.11b. Minimum ignition energies for each of the fuels had been determined in the laboratory with a simulated radiant source. In the field minimum ignition energies were determined by exposure of representative fuels placed at several predicted thermal energy levels expected to bracket the desired effect. Only those fuels which ignited in laboratory tests at thermal energies below 20 cal/cm^2 were studied.

In addition to the study of urban vulnerability to fire under Project 8.11a, five miniature houses were constructed to provide illustrative footage of time-technical photography for use in demonstrating fire hazards from atomic weapons. Three of the houses were intended to demonstrate ignition from exterior kindling fuels and two from interior fuels.

Several experimenters have shown that thermal radiation from atomic weapons causes only transient flames in massive wood or on exterior surfaces of appreciably thick combustible material. These flames usually die out with the fading of the radiant pulse. If not, the flames are always snuffed out by the passing shock wave. The case is quite different, however, with thin kindling fuels, especially fuels such as crumpled newspaper, dead vegetation, folded curtains, oily waste, excelsior, and the like. In compacted fine fuels the contrast is so great that, in many cases, the subsequent arrival of the shock wave actually drives the persistent flame into the mass of fuel and enhances greatly the probability that the flames will persist through the blast. It has also been shown that decayed massive wood, if unprotected by paint, irradiated by thermal radiation may ignite, continue to glow through the shock wave, and subsequently burst into flame.

Fuels in which flame is likely to persist through the passing shock wave are potential sources of disastrous fires if the ignitions are established in the vicinity of more massive combustible fuels, such as the interiors or exteriors of houses, fences, interiors of automobiles, and military supply dumps. One of the objectives of this project and of Project 8.11b was to develop methods, based upon laboratory and field results, for predicting the incidence

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in urban areas of the primary ignitions which may occur and persist through the shock wave.

For the some 20 kindling fuels exposed under Project 8.11a in Shots 9 and 10, the minimum ignition energies as found with the laboratory source averaged 29 per cent higher than the energies found in the field. Using this conversion factor, ignition energies may be predicted from data obtained with the laboratory source for other kindling fuels not tested in the field. It is anticipated that with further laboratory tests employing a suitably modified radiant source, the results from this project may be satisfactorily extended, without significant additional field work, for application to weapons with yields larger than 10 to 100 KT (i.e., weapons with longer and lower average intensity pulses) which is the present limit for application of the Project 8.11a results.

The timed-technical photography of the five miniature houses exposed at Shot 9, together with supplementary off-site footage, was incorporated into two FCDA films, each entitled *House in the Middle*, one a 6-min film, the other a 13-min film.

B.7.11 Project 8.11b: Initiation and Persistence of Primary Fires (Ignitable Litter)
Agency: Division of Fire Research, Forest Service, USDA
Report Title: Ignition and Persistent Fires Resulting from Atomic Explosions—Exterior Kindling Fuels, WT-775
Project Officer: W. L. Fons

The close relation between this project and Project 8.11a has been noted. The results of laboratory and field studies under both Projects 8.11a and 8.11b are important to the over-all problem of target analysis for fire probability in urban areas for offensive and defensive military operations.

The techniques used in the field for this project were the same as those described for Project 8.11a. Among the kindling fuels tested were various types of waste paper, mops, rags, pine needles, car seats (in automobiles and separately exposed), and awning canvas. This project participated in Shots 4, 9, and 10.

Minimum ignition energies were established for those exterior kindling fuels which are encountered in urban areas in this country. The conditions under which ignitions of these fuels will occur with lower yield weapons (10 to 100 KT) have been firmly established as the result of field studies under this project and related laboratory studies. It is anticipated that ignition energies may be extended through appropriate laboratory studies to the larger yield weapons with characteristically longer radiant pulses, thus obviating any need for further extensive field studies.

The establishment of primary ignitions in automobiles from thermal radiation was shown to be relatively an unimportant hazard.

B.7.12 Project 8.12a: Measurement of Velocity of Sound
Agency: Navy Electronics Laboratory
Report Title: Sound Velocities near the Ground in the Vicinity of an Atomic Explosion, WT-776
Project Officer: H. C. Silent

The primary objective of this project was to determine the velocity of sound near the ground before arrival of the shock wave as a function of distance for Shots 9 and 10. Secondary objectives of the project were to determine the effects of different surfaces and of white and black smoke on the preshock sound velocities and, also, to measure the velocity of the wind behind the shock front. Data on sound velocities close to the surface prior to shock arrival are a useful tool for correlating precursor pressure wave studies since shock wave behavior is dependent upon sonic velocity.

The basic instrumentation consisted of transducer pairs mounted $3\frac{1}{2}$ and 10 ft above the ground at Intended Ground Zero (IGZ) and at several intermediate stations out to 5000 ft along the blast line and to an equal distance along the smoke line. Each pair of transducers consisted of one speaker and one microphone separated by an 8-ft path length.

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For the wind velocity measurements two stations, one at 2000 ft and the other at 3500 ft from IGZ on the blast line, were equipped with three mutually perpendicular transducer pairs to measure the vectorial components of the wind. In the experiment on surface effects on Shot 9, transducer pairs, with the 8-ft sound path, were mounted $3\frac{1}{4}$ ft above surfaces of mat of white fir boughs and of Frenchman Flat soil at distances of 1000 and 2000 ft from IGZ on the blast line. For Shot 10 the fir boughs were replaced with surfaces of blackened sheet iron.

On Shot 9 sound velocities attained prior to shock arrival over Frenchman Flat soil at $3\frac{1}{2}$ and 10 ft elevations ranged up to 2000 ft/sec and 1400 ft/sec (ambient velocity 1100 ft/sec), respectively. Above fir boughs the velocities attained were considerably higher than over sand, being 3000 ft/sec or more at $3\frac{1}{4}$ ft elevation. Over the sand coated with a thin cover of asphalt (around IGZ), instruments at $3\frac{1}{2}$ ft elevation indicated that the sonic velocity was lower than that over sand. Since the smoke was not activated on Shot 9, no data on sonic velocities beneath scattering white smoke were obtained.

On Shot 10 the destructive effect of the blast forced the NEL shelter located at 500 ft from IGZ into the ground, severing all the instrument cables running from this point through Ground Zero to the smoke line. Also the early arrival of the shock wave prevented recovery of the closer-in instruments from the electromagnetic transients induced at zero time. In general, very few reliable data on sonic velocities were obtained from Shot 10. A single sound velocity result over blackened iron on this shot seemed to indicate, as anticipated, that the velocity is lower over metal due to dependence upon the conductive process only for transfer of heat to the air.

Due to failure of instruments to recover sufficiently soon after shock arrival, data on sonic velocities with the particle velocity meters could not be reduced to yield particle velocities within the shock wave.

The NEL sound velocity data on surface influences (fir boughs, asphalt, sheet iron, and sand) were, perhaps, the most significant finding from this project.

It does not appear advisable, at least with the present design of NEL velocity meters, to utilize the NEL equipment for postshock measurements. The NEL equipment should be modified so as to reduce greatly or eliminate the electromagnetic transient effect if the NEL technique is to be employed again at field tests.

B.7.13 Project 8.12b: Precursor Shock Study
Agency: David Taylor Model Basin
Report Title: Supplementary Pressure Measurements, WT-777
Project Officer: G. W. Cook

The objective of this project was to determine whether a shock wave may be generated prior to the arrival of the main shock by exposure of a surface to thermal radiation from an atomic weapon. Although the hot air boundary layer hypothesis was generally accepted as the mechanism for precursor generation, this experiment was designed to record the possible existence of a signficant thermal shock.

Sensitive capacitance type pressure gages were used to measure pressures at the center of 10 × 10 thermal panels inclined toward the point of detonation on Shots 9 and 10 at ranges of 1500 and 3000 ft from IGZ. These inclined surfaces consisted of black asphalt roofing paper (a highly absorbing, smoke-producing surface), black ceramic tile (an absorbing but nonreactive surface), and Frenchman Flat soil molded with water (an absorbing, popcorning surface). A fourth gage was mounted at ground level at each of the two stations for reference purposes. These panels were inclined at angles such that they were approximately perpendicular to the thermal radiation from both of these air bursts in order to enhance the values of the incident radiant energy.

No significant preshock pressures were observed on Shots 9 and 10 that would substantiate the thermal shock hypothesis as a mechanism for precursor generation. Several minor preshock signals were observed on Shot 10 which occurred at the time of the thermal pulse. There is evidence to believe that this gage response was due to the effect of electromagnetic and thermal radiation. There appear to be conflicting results on thermal shock phenomena from

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other projects. Project 1.1a and 1.2 reports no preshock measurements with either mechanical or electronic gages in this region, whereas Project 1.1d reports small preshock pressures for both Shots 9 and 10 as recorded on electronic gages. It is not presently known whether such preshock pressures are real or whether they are within the uncertainties of the instrumentation system.

It is possible that under certain conditions preshock pressures may result from thermal shock in those regions which are close to Ground Zero. However, it does not appear that there is sufficient energy available for purposes of precursor formation or propagation. Furthermore, thermal shock is not considered significant since it may be expected to occur only under those conditions favorable to the formation of a thermal layer at the surface and the subsequent development of a precursor at slightly greater ranges. It is considered that this project has demonstrated that further study of thermal shock phenomena is not warranted.

B.7.14 Project 8.13: A Study of Fire Retardant Paints
Agency: Engineer Research and Development Laboratories
Report Title: Study of Fire Retardant Paint, WT-778
Project Officer: H. Miller

The objective of this project was to obtain exposure of a number of test paint panels to the radiant energy of the bomb. The paints exposed were fire retardant paints which, subsequently, were tested in the laboratory to determine residual fire retardancy of the exposed surfaces.

Although such paints are not proposed for inhibiting primary ignitions from the weapon, they may have application for retarding combustion if massive fuels (see Project 8.11a) from nearby ignition points established either in kindling fuels (primary ignitions) or in fuels ignited by broken gas lines, electrical lines, etc. (secondary fires). In such cases the residual fire retardancy of the irradiated surfaces would be of interest.

Wood panels painted with three fire retardant paints and two non-fire retardant paints were successfully exposed on Shot 9 to three different levels of thermal energy. Subsequent tests at ERDL of the residual fire retardancy of the exposed panels indicated no serious decrease in the fire retardant properties of the exposed panels even at the highest energy of exposure, i.e., 31 cal/cm^2. The results indicate that the role of fire retardant paints in inhibiting the spread of fire will not be seriously affected by exposure to thermal radiation in most cases. The project was not designed, however, to indicate the enhanced ignitability of irradiated wood surfaces adjacent to kindling fuels ignited by the thermal radiation.

There are no recommendations for future field tests.

B.8 PROGRAM 9—TECHNICAL PHOTOGRAPHY
Program Director: W. R. Greer

B.8.1 Project 9.1: Technical Photography
Agencies: Edgerton, Germeshausen & Grier and U. S. Signal Corps
Report Title: Technical Photography, WT-779
Project Officer: Maj W. R. Greer, USA

Project 9.1 was established to provide a centralized organization responsible for all photography, other than documentary and historical, required by the various military effects projects participating under the direction of Programs 1 to 9. Documentary and historical motion picture photography was performed by Lookout Mountain Laboratory.

The still photography and the pre- and post-test motion picture photography of this project was performed by personnel and equipment furnished by the U. S. Army Signal Corps. This photography was done for the various projects for record purposes. Over 85,000 prints were processed from approximately 10,000 ft of exposed motion picture film.

The motion picture technical photography at shot time was performed by Edgerton, Germeshausen & Grier, under contract, and included all zero time photography desired by the projects. This phase was accomplished by the use of motion picture cameras operating be-

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tween the limits of 2 frames per minute and 2500 frames per second. A total of 193 cameras on 100 steel towers of various heights were used on Shot 9. A lesser, but still considerable, number of cameras were used on Shot 10; 94 cameras and 50 towers. The tower's ranged in heights from 5 to 25 ft.

In general, the technical photography gave exceedingly good results, and those camera targets which were beyond 2500 ft from Ground Zero and several feet above the ground gave outstanding results. Those targets which were closer than 2500 ft or near the ground gave fair to poor results.

B.8.2 Project 9.6: Stabilization (Production)
Agency: Field Command, Armed Forces Special Weapons Project
Report Title: Production Stabilization, WT-780
Project Officer: Capt C. S. Adler, USA

The objective of Project 9.6 was to provide stabilized areas for the photographic stations used on Shots 9 and 10 in order to eliminate the thermal and blast dust.

Designated areas were stabilized with a sand-cement mixture approximately 2 in. thick, the exact area stabilized depending on the distance the camera stations were from Ground Zero. These various distances were derived from curves showing estimated particle transport vs blast pressures or ground ranges. Approximately 700,000 sq yd of the Frenchman Flat lake bed were stabilized. The stabilization specification was established by the U. S. Corps of Engineers at the request of AFSWP.

The results from this production stabilization were excellent at all distances over 2000 ft from Ground Zero. It may be said that the success of the technical motion picture photography was dependent to a large extent on the success of this stabilization program.

B.8.3 Project 9.7: Stabilization (Experimental)
Agency: U. S. Corps of Engineers
Report Title: Experimental Soil Stabilization, WT-781
Project Officer: Capt C. S. Adler, USA

Project 9.7 was established to test the resistance of several types of surfaces to the effects of thermal and blast from nuclear detonation using specifications which were not used in the production stabilization effort.

On the basis of previously conducted laboratory studies, several promising stabilizing agents were tested. Tests included sand-cement, sodium silicate, and lignin in various solutions. The experimental stabilized surfaces were photographed with zero time photography so as to record the effects of thermal radiation. In addition the stabilized surfaces were exposed for prolonged periods of time to test their perviousness to the elements of Frenchman Flat.

The sodium silicate worked well with incident thermal energies up to 50 cal/cm^2 as did the cement mixture. Up to peak overpressures of 50 psi, the cement mixture was quite satisfactory, whereas the sodium silicate solution withstood pressures up to only 15 psi. No materials tested are recommended for over 60 psi. In addition, it is to be noted that the sodium silicate stabilization will not support traffic.

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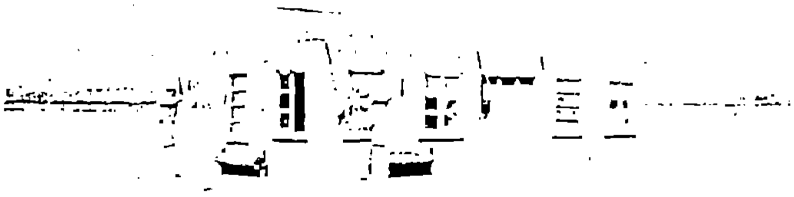

Fig. B.19 — Structure 3.16a After Shot 10.

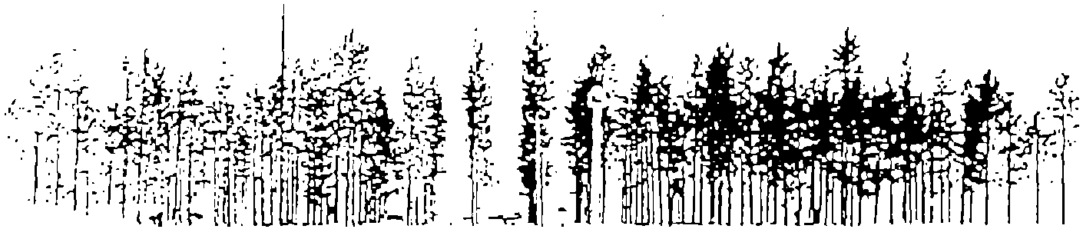

Fig. B.20 — Tree Stand Prior to Shot 9.

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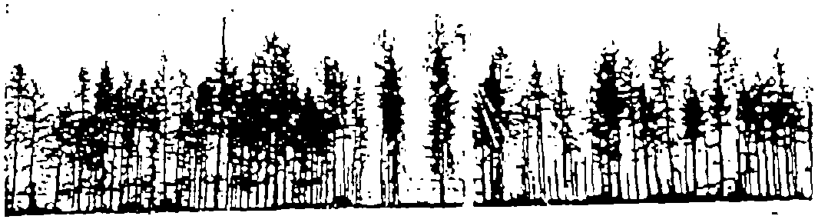

Fig. B.21 — Tree Stand After Shot 9.

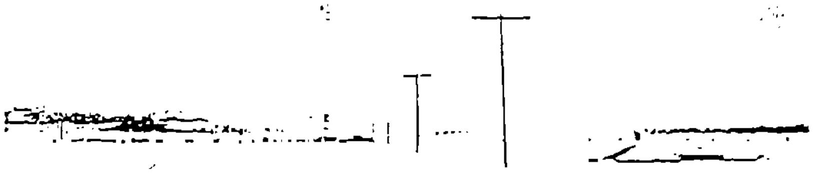

Fig. B.22 — Radial Pole Line with Aluminum Towers in the Distance.

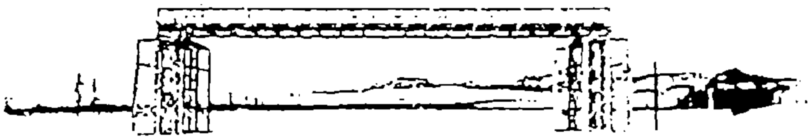

Fig. B.23 — Bailey Bridge at 4100 Ft Prior to Shot 9.

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